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GEOPHYSICAL INVESTIGATION AT SOLID WASTE MANAGEMENT UNIT NO. 3 FORT BUCHANAN, PUERTO RICO

by

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13. ABSTRACT *(Maximum 200 words)*

Results of a comprehensive, integrated geophysical investigation of Solid Waste Management Unit No. 3 (SWMU No. 3) at Fort Buchanan, Puerto Rico (FTB), are presented. In 1977, approximately one ton (one truckload) of various pesticides reportedly were buried at SWMU No. 3. The precise location of the burial trench is not available from records. The suspected burial trench lies in the vicinity of a 66-in. diameter water main which supplies the city of San Juan with potable drinking water. There is concern over the possibility of pesticide-contaminated groundwater infiltrating through the line's seals when the line is depressurized during periodic maintenance. Investigations at this site have been ongoing since 1983 and include groundwater monitoring, trenching, and soil sampling. The geophysical investigation presented in this report was designed to detect anomalous conditions indicative of a possible burial trench.

The geophysical program included electromagnetic induction and magnetic survey methods. The results of the various surveys were integrated and numerous anomalous areas were interpreted. Anomalies warranting further investigation were presented along with a priority ranking.

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PREFACE

A geophysical survey was conducted at Fort Buchanan (FTB), Puerto Rico, by personnel of the Geotechnical Laboratory (GL), US Army Engineer Waterways Experiment Station (WES), between 2 and 10 October 1991. The work was performed for the US Army Toxic and Hazardous Materials Agency (USATHAMA), Aberdeen Proving Ground, Maryland. The USATHAMA Technical Monitor was Mr. Dennis Bowser.

This report was prepared by Messrs. José L. Llopis and Michael K. Sharp, Earthquake Engineering and Geosciences Division (EEGD). The work was performed under the direct supervision of Mr. Joseph R. Curro, Jr., Chief, Engineering Geophysics Branch. The work was performed under the general supervision of Drs. A. G. Franklin, Chief, EEGD, and William F. Marcuson III, Chief, GL.

Field work and data analysis were performed by Messrs. Llopis and Sharp. Mr. Angel Perez, Directorate of Engineering and Housing, FTB, provided invaluable support during the site preparation phase of this study.

Dr. Robert W. Whalin was Director of WES. COL Leonard G. Hassell, EN, was Commander and Deputy Director.

CONTENTS

CONVERSION FACTOR, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
Fahrenheit degrees	5/9	Celsius degrees or Kelvins*
feet	0.3048	metres
gallons	3.785412	liters
gamma	1.0	nanotesla
inches	2.54	centimetres
miles (US statute)	1.609347	kilometres
millimhos per foot	3.28	millimhos per metre
miilimhos per foot	3.28	milliSiemens per metre
pounds (mass)	0.4535924	kilograms
tons (2,000 pounds, mass)	907.2	kilograms

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: C = (F - 32) * (5/9). To obtain Kelvin (K) readings, use: K = (F - 32) * (5/9) + 273.15.

GEOPHYSICAL INVESTIGATION AT
SOLID WASTE MANAGEMENT UNIT NO. 3,
FORT BUCHANAN, PUERTO RICO

PART 1: INTRODUCTION

Background

1. An onsite Installation Assessment (IA) was conducted between 30 August and 3 September 1982 at Fort Buchanan (FTB), Puerto Rico. The purpose of the IA was to determine the existence of toxic and hazardous materials and related contamination at FTB, emphasizing those substances posing a potential for migration off the installation (McMaster et al. 1984). As a result of the 1982 IA one site, Solid Waste Management Unit (SWMU) No. 3, was identified as warranting further assessment.

2. In 1990 the Puerto Rico Environmental Quality Board (EQB) completed a Resources Conservation and Recovery Act (RCRA) Facility Assessment (RFA) for FTB. The EQB conducted this activity by agreement with the US Environmental Protection Agency (EPA) under the authority of RCRA. On the basis of the 1990 RFA and other documentation, the EPA determined that there was the potential for significant environmental risk at SWMU No. 3.

3. In 1977 approximately 1 ton (1 truckload) of various pesticides reportedly were buried in a shallow trench at SWMU No. 3. The suspected buried pesticides are reported as consisting of Chlordane, p,p'-DDE, and Heptachlor. McMaster et al. (1984) reported that the pesticides, mostly in bags and boxes, but also contained in numerous (10 to 20) 5-gal metal containers, were deposited into a trench estimated to be 6 ft deep, 18 ft wide, and 45 to 90 ft long. The trench was then backfilled with trees and the original soil and compacted with a bulldozer. The precise location of the burial trench is not available from records.

4. In 1980, the Puerto Rico Aqueduct and Sewage Authority (PRASA) installed a potable water supply main across FTB connecting the San Juan and Bayamon water supply systems. The 66-in dia main is constructed of reinforced concrete and is buried at a depth of approximately 10 ft. The PRASA main passes by the suspected pesticide burial site and may even intersect it. The EPA is concerned that when the main is depressurized, during periodic maintenance, infiltration of contaminated groundwater through the line's seals may occur. Two other EPA concerns are;

a. The gravel underlayment of the water main could act as a conduit for the off-site migration of contaminated groundwater.

b. Many of the formations which outcrop on the site serve as aquifers and could potentially be contaminated. These aquifers have been designated as an alternative potable water supply for the area. The site is part of the recharge area for these aquifers.

5. The US Army Toxic and Hazardous Materials Agency (USATHAMA) conducted a limited contamination assessment in 1983 to identify the chemical identity of the pesticides and the composition and the geometry of the subsurface materials. Seventeen shallow and 1 deep soil boring were placed and various trenches excavated at SWMU No. 3 to assess site conditions and to attempt to locate the burial site. No firm evidence for the burial of the pesticides was found as a result of these tests (McMaster et al. 1984).

Objectives

6. The US Army Engineer Waterways Experiment Station (WES) conducted a geophysical survey at FTB to delineate anomalies indicative of buried waste, waste containers, and the boundaries of the burial trench. Electromagnetic (EM) and magnetic surveys were conducted at the site to meet the above objectives.

PART II: DISPOSAL AREA CHARACTERISTICS

Location of Disposal Area

7. FTB is located approximately 6 miles southwest of San Juan, Puerto Rico as shown in Figure 1. SWMU No. 3 is located in the northwestern part of FTB along the perimeter fence bordering Highway P.R. 28 (Figure 2). The suspected location of the pesticide burial trench at SWMU No. 3 is shown in Figure 2.

General Physical Conditions

8. SWMU No. 3 encompasses an area approximately 100 ft wide by 1500 ft in length with its major axis oriented roughly in a east-west direction (Figure 2). The site is relatively flat and can pond precipitation for a period of time. Because of the tropical marine climate (high rainfall and warm temperatures) the site is heavily vegetated with small to large trees and head-high grasses. Prior to the survey the site was cleared of vegetation and leveled with a bulldozer.

9. As previously mentioned, one deep and seventeen shallow exploratory borings were placed and two trenches excavated at SWMU No.3. Figure 3 shows the location of the soil borings and trenches used for the 1983 contamination assessment. The deep boring was augured to a depth of 40 ft whereas, the shallow borings were augured to depths ranging between 3 and 8 ft. The deep soil boring indicates that the water level is 33 ft below the ground surface, or approximately 27 ft below the base of the trench as reported in McMaster et al. (1984). Logs of borings indicate that the soil at the site is generally a clay from 0 to 19 ft deep, silty-clay, clay, clayey-silt and silty-, clayey-sand from 19 to 33 ft deep, underlain by badly weathered clayey-, sandy-limestone (McMaster et al. 1984). Therefore, the bottoms of the trenches are expected to be in soil. None of the borings penetrated the suspected trench. The log for the deep boring as reported in McMaster et al. (1984) is presented in Figure 4.

10. The two trenches were dug by backhoe to give a visual profile of the soil. The trenches were aligned with the major axis perpendicular to the installation boundary and were between 20 and 25 ft long, 5 ft wide and 6 to 7 ft deep. The trenches intersected the PRASA water main. Neither trench showed evidence of any backfilled trenches other than the one dug for the PRASA water main (McMaster et al. 1984). A schematic cross section of SWMU No. 3, showing the suspected location of the trench relative to the PRASA water main, is shown in Figure 5.

11. The geophysical field work was conducted during 2 and 10 October 1991. The temperature at the site during the performance of the field work ranged between approximately 85° and 95° F. The water table is deemed to have little affect on the test results since the depth to the top of the water table is greater than 33 ft and because it is assumed that the water table elevation did not change significantly during the survey period.

PART III: GEOPHYSICAL TEST PRINCIPLES AND FIELD PROCEDURES

Geophysical Test Principles

Electromagnetic surveys

12. The EM technique is used to measure differences in terrain conductivity. Like electrical resistivity, conductivity is affected by differences in soil porosity, water content chemical nature of the ground water and soil, and the physical nature of the soil. In fact, for a homogeneous earth the true conductivity is the reciprocal of the true resistivity. Some advantages of using the EM over the electrical resistivity technique are (a) less sensitivity to localized resistivity inhomogeneities, (b) no direct contact with the ground required, thus no current injection problems, (c) smaller crew size required, and (d) rapid measurements (McNeil, 1980).

13. The EM equipment used in this survey consists of transmitter and receiver coil set a fixed distance apart. The transmitter coil is energized with an alternating current at a frequency of 9.8 kHz to produce a time-varying magnetic field which induces small eddy currents in the ground. These currents then generate a secondary magnetic field which is sensed together with the primary field by the receiver coil. The units of conductivity are millimhos per meter (mmho/m) or in the SI system milliSiemens per meter (mS/m). The EM data are then presented in profile plots or as isoconductivity contours if data are obtained in a grid form. A more thorough discussion on EM theory and field procedures is given by Butler (1986), Telford et al. (1973) and Nabighian (1983).

14. There are two components of the induced magnetic field measured by the EM equipment. The first is the quadrature phase component, which gives the ground conductivity measurement. The second is the in-phase component, which is used primarily for calibration purposes. However, the in-phase component is significantly more sensitive to large metallic objects and hence very useful when looking for buried metal containers (Geonics, 1984). The 5 gal. containers are assumed to be large enough to be detected by the in-phase component. When measuring the in-phase component the true zero level is not known since the reference level is arbitrarily set by the operator. Therefore, the measurements collected in this mode are relative to a reference level and have arbitrary units of parts per thousand (ppt).

15. A Geonics model EM-31 ground conductivity meter was used to survey the site. The EM-31 has an intercoil spacing of 12 ft and has an effective depth of exploration of about 20 ft (Geonics, 1984). The EM-31 meter reading is a weighted average of the earth's conductivity as a function of depth. A thorough investigation to a depth of 12 ft is usually possible, but below that

depth the effect of conductive anomalies becomes more difficult to distinguish. The EM-31 when carried at a usual height of approximately 3 ft, is most sensitive to features at a depth of about 1 ft. Half of the instrument's readings results from features shallower than about 9 ft, and half from below that depth (Bevan 1983). Figure 6 more clearly illustrates the effect of depth on instrument sensitivity; the dashed lines depict the sensitivity of the instrument to objects between it and the ground. The instrument can be operated in both a horizontal and vertical dipole orientation (Figure 7) with correspondingly different effective depths of exploration. The instrument is normally operated with the dipoles vertically oriented (coils oriented horizontally and co-planar) which gives the maximum depth of penetration. The instrument can be operated in a continuous or a discrete mode. Figure 8 shows an EM-31 conductivity meter in use.

Magnetic surveys

16. The magnetic method of surveying is based on the ability to measure local disturbances of the earth's magnetic field. Magnetic anomalies are caused by two different types of magnetism: induced and remanent magnetization (Parasnis 1966 and Breiner 1973). Remanent magnetization is a permanent magnetic moment per unit volume whereas induced magnetization is temporary magnetization that disappears if the material is removed from a magnetic field. Generally, the induced magnetization is parallel with and proportional to the inducing field (Barrows and Rocchio 1990). The remanent magnetism of a material depends on the thermal and magnetic history of the body, and is independent of the field in which it is measured (Breiner 1973).

17. An EDA OMNI IV proton-precession magnetometer, as shown in Figure 9, was used to measure the total field intensity of the local magnetic field. The local magnetic field is the vector sum of the field of the local magnetized materials (local disturbance) and the ambient (undisturbed) magnetic field. Figure 10 shows the ambient earth's field as 50,000 nanoteslas (nT) with a local disturbance of 10 nT. Figure 10 shows that the quantity measured with the magnetometer is the resultant total field with a value of 50,006 nT. The magnetometer was also used with dual sensors thereby allowing the gradient of the total magnetic field to be measured. The gradient is taken by measuring the total field at the two sensors which are fixed a small distance apart. The difference in values between the two sensors divided by their separation approximates the gradient measured at the midpoint of the sensor spacing. Two advantages of using the magnetic gradient are that 1. the regional magnetic gradient is filtered out thus local anomalies are better defined and 2. since the two readings are taken a short time apart magnetic storm effects and diurnal magnetic variations are essentially removed (Breiner, 1973). The magnetometer used in this survey has an absolute

accuracy of approximately ±1 nT. For reference, the earth's magnetic field varies from approximately 60,000 nT at the poles to 30,000 nT at the equator (the nominal field strength at FTB is 45,000 nT).

18. A magnetic anomaly represents a local disturbance in the earth's magnetic field which arises from a localized change in magnetization, or magnetization contrast. The observed anomaly expresses the net effect of the induced and remanent magnetization and the earth's ambient magnetic field. Depth of detection of a localized subsurface feature depends on its mass, magnetization, shape and orientation, and state of deterioration.

Ground penetrating radar

19. Ground penetrating radar (GPR) is a geophysical subsurface exploration method using high frequency EM waves. The GPR system consists of a transmitting and a receiving antenna. The transmitting antenna transmits an EM signal into the ground and is reflected by materials having contrasting electrical properties back to the receiving antenna. These signals are then amplified, processed and recorded to provide a continuous profile of the subsurface.

20. The transmitted EM waves respond to changes in soil and rock conditions having sufficiently different electrical properties such as those caused by clay content, soil moisture or ground water, water salinity, cementation, man-made objects, voids, etc. The depth of exploration is determined by the electrical properties of the soil or rock as well as by the power of the transmitting antenna. The primary disadvantage to GPR is its extremely site specific applicability; the presence of high-clay content soils in the shallow subsurface (such as exist at this site) will generally defeat the application of GPR (Olhoeft 1984). High water contents in the shallow subsurface and shallow water tables can also limit the applicability of GPR at some sites. A general rule is that GPR should not be applied to projects in which the mapping objective is greater than 50 ft in depth. For shallow mapping applications at sites with low clay content soils, GPR will generally have the best vertical and horizontal resolution of any geophysical method (Butler and Llopis, 1990).

21. A GSSI System 8 radar with a 120 MHz antenna as shown in Figure 11 was tested at the site to determine the feasibility of using GPR. It was concluded that GPR would not be feasible for conducting the survey because of poor test results which were presumably due to the high clay content found at the site. In addition, during clearing operations, roughened surface conditions were created when bulldozer track marks in the clay were sun-baked to a rock-hard state. These hardened track marks would have prevented dragging the radar antenna across the site.

Field Methods

22. A rectangular-shaped grid measuring 100 ft by 1500 ft was established to encompass the area of interest (Figure 12). The grid stations at the site were marked at 20 ft intervals by implanting polyvinyl chloride (PVC) stakes into the ground. PVC stakes were used to prevent interference with the geophysical tests conducted at the site. Magnetic and EM-31 readings were taken at 10 ft intervals over the entire gridded area. The positions of intermediate stations (between flagged stations) were estimated visually.

23. The EM-31 data were taken both in the quadrature phase (conductivity) and in the in-phase (magnetic susceptibility) mode at each measurement station. The measurements were recorded on a digital data logger as shown in Figure 13 and transferred to a portable field computer at the conclusion of a survey day.

24. Total magnetic field and magnetic gradient readings were also taken at each survey point. The data were collected and stored in internal memory of the magnetometer and transferred to a portable field computer at the conclusion of a survey day.

PART IV: GEOPHYSICAL TEST RESULTS

Presentation of Test Results

25. The results of the four survey sets conducted at the site are presented in two fashions; each survey set is presented as a profile line map and as a contour (two dimensional) map of the measured values. The profile maps for the EM-31 quadrature phase, EM-31 in-phase, total magnetic field, and magnetic gradient are presented in Figures 14 through 17, respectively. The profile lines are oriented in a north-south fashion with higher values on the right-hand side of each profile line. The profile lines show relative values and are used in identifying trends in the data and anomalous characteristics.

26. The contour maps for the EM-31 quadrature phase, EM-31 in-phase, total magnetic field, and magnetic gradient are presented in Figures 18 through 21, respectively. The color scheme used for each of the contour plots is; hot colors (reds) indicate relatively high values whereas, the cold colors (blues) indicate relatively low values.

EM-31 Results

Quadrature phase (conductivity).

27. The results of the EM-31 conductivity survey are presented in Figures 14 and 18. Figure 14 presents the profile lines and various anomalous areas can be seen. It is noted that the perimeter fence, located 10 ft north of the site, has an influence on the conductivity readings out to a distance of approximately 40 ft. Figure 18, contour plot, shows many anomalous areas. The anomalous zones were based by selecting areas having values above those of background readings which for this site happens to be between 40 and 60 mS/m. Based on these background values the anomalous zones were interpreted and are shown in Figure 18.

In-phase.

28. The EM-31 in-phase results are presented in Figures 15 and 19. The profile lines shown in Figure 15 indicate various anomalous areas. As was the case for the conductivity study the readings for the in-phase survey are also affected by the perimeter fence out to a distance of approximately 40 ft. The survey results shown in Figure 19 indicate that the background values for this site range between approximately -0.2 and 0.4 ppt. The data indicate several

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anomalously high and low values. The anomalous areas may be indicative of buried metallic objects. The anomalous areas are noted in Figure 19.

Magnetometer Results

Total magnetic field.

29. The results of the total magnetic field survey are shown in Figures 16 and 20. Anomalous areas can be seen in Figure 16 and 20. Some of the anomalies shown in Figures 16 and 20 correlate very well with visible metallic debris scattered across the site.

Magnetic gradient.

30. The results of the magnetic gradient survey are presented in Figures 17 and 21. The locations of anomalies interpreted from the magnetic gradient survey are similar to those for the total magnetic field survey. Figure 21 shows the interpreted anomalies from the magnetic gradient survey.

PART V: DATA INTERPRETATION

31. In determining which of the anomalous areas are to be considered significant, several factors must be considered. Anomaly detection is limited by instrument accuracy and local "noise" or variations in the measurements caused by factors not associated with the anomalies of interest. For the anomaly to be significant, it must be two to three times greater than these factors. Since the anomaly amplitude, spatial extent, and wavelength are the keys to detection, the size and depth of the feature causing the anomaly are important factors in determining detectability and resolution. The intensity of the anomaly is also a function of the degree of contrast in material properties between the anomaly and the surrounding material. Based upon the methods employed, noise conditions at the site and the assumption that the target objects are relatively shallow (less than 10 ft), the areas indicated as anomalous in Part IV (Results) can be considered as significant. In the interpretation of the results, the above criteria were utilized and refer to anomalies caused by localized contrasts in magnetic susceptibility and electrical conductivity.

32. The visible debris, which was considered to have the potential to affect the geophysical tests, was mapped to aid in distinguishing anomalies caused by subsurface versus those anomalies caused by surface features (Figure 22). Figure 22 shows the presence of steel, concrete slabs, and chunks of concrete capable of interfering with the geophysical test results. In order to facilitate visualizing the results of the various surveys and to correlate the interpreted anomalies with visible debris found at the site, an integrated anomaly map was prepared (Figure 23). Figure 23 was prepared by superimposing the anomalies interpreted from the geophysical surveys onto the visible debris map. Figure 23 shows the anomaly type, anomaly location and its approximate areal extent.

33. The individual anomalies shown in Figure 23 were gathered into anomaly groups and are shown in Figure 24. The groups were located by outlining the anomalous areas shown in the Integrated Anomaly Map (Figure 23). In some cases the groups contain anomalies identified from more than one test while other groups are based on results of a single test. The anomaly groups shown in Figure 24 are tabulated below along with a brief description and interpretation.

Anom. Group No.	EM-31		Mag.		Description of Anomalies
	Q	I	M	G	
1,2		X			Small area, probably small metal buried pipe associated with water point.
3,5, 6,8,			X		Small target, probably small buried metallic object.
4,7				X	Small target, probably small buried metallic object.
9	X		X	X	Anomaly probably due to metallic manhole cover.
10			X		Anomaly probably due to visible iron pipe.
11			X	X	Anomaly probably due to small metallic object.
12		X	X		Anomaly probably due to small metallic object.
13	X				Anomaly may be due to localized soil disturbance or difference.
14	X	X	X	X	Anomaly probably due to metallic manhole cover.
15,21 39			X	X	Anomaly may be due to buried metallic debris and/or perimeter fence.
16,20				X	Anomaly may be due to buried nearby metallic object.
17			X	X	Probably a small buried metallic object.
18,22 31			X		Anomaly may be due to buried nearby metallic object or concrete chunks.
19	X				EM-31 QP is relatively high in this area. This may be caused by an increase in clay, water content, or ground water conductivity.

Anom. Group No.	EM-31		Mag.		Description of Anomalies
	Q	I	M	G	
23,33	X			X	Anomaly probably due to buried metal objects and/or change in soil type or concrete chunks.
24	X	X			Anomaly probably due to buried metal objects and/or change in soil type or concrete chunks.
25,30	X				Anomaly probably due to buried metal objects and/or change in soil type or concrete chunks.
26,27 36			X		Anomaly probably caused by buried metal or concrete chunks.
28			X		Anomaly may be due to visible steel pipe and large chunk of reinforced concrete and/or steel fence.
29		X			Anomaly may be due to small buried metallic object.
32,43	X	X	X	X	Anomaly may be due to buried metal or concrete, change in soil type (increase in clay content, greater water content, or higher water conductivity) or a combination of all of the above.
34			X		Anomaly may be due to nearby concrete culvert, and/or perimeter fence.
35				X	Anomaly may be due to nearby exposed steel chunk and/or perimeter fence.
37,41			X		Anomaly may be caused by nearby concrete chunks or buried metallic object.
38		X	X	X	Anomaly may be caused by nearby buried metallic object and/or perimeter fence.
40	X	X	X		Anomaly may be due to exposed concrete chunks and/or buried metal object.

Anom. Group No.	EM-31		Mag.		Description of Anomalies
	Q	I	M	G	
42				X	Anomaly may be due to exposed concrete chunks and/or buried metal object.
44	X	X			Anomaly probably due to buried metal object, perimeter fence and/or change in soil type or water conductivity.
45			X	X	Anomaly may be due to exposed concrete chunks, buried metal object or interference from perimeter fence.

Note: Q = EM quadrature phase
I = EM in-phase
M = Total magnetic field
G = Magnetic gradient

34. The interpretation of the geophysical anomalies discussed above was used to construct a map showing the priority of areas to be further investigated (Figure 25). The priority values shown in Figure 25 range in value between 1 (highest priority) and 5 (lowest priority). The priority values on the Priority Map are based on the number, kind, and size of anomalies interpreted from the geophysical surveys and the proximity of the anomalies to mapped survey-interfering debris. It is noted that, in general, it is difficult to apply an accurate priority number to the anomalies occurring along the metallic northern perimeter fence because of its interference on the geophysical tests.

PART VI: CONCLUSIONS AND RECOMMENDATIONS

35. A geophysical investigation using magnetic and electromagnetic methods was conducted at Fort Buchanan in an effort to detect and delineate a suspected waste pesticide burial site. Several areas at the surveyed site were interpreted as having anomalous readings and were noted. Many of the anomalies are interpreted as being caused either by buried concrete chunks and/or metallic debris. The geophysical tests were considerably interfered with by the metallic and concrete debris dispersed about the site and the perimeter fence. It is possible that the noted anomalous areas interpreted from the geophysical tests may be caused by a burial trench or by materials contained within it. Also noted was the priority in which these anomalous areas should be further investigated.

35. If the decision to proceed to Corrective Measures is made, it is recommended that selected geophysical anomalies be excavated by backhoe or similar excavator to determine the nature (e.g. solid, liquid, contained or uncontained) and extent of the anomalies. If the location of the pesticide trench is ascertained, options for disposition of excavated material, including reinternment and closure of the site, should be considered at that time.

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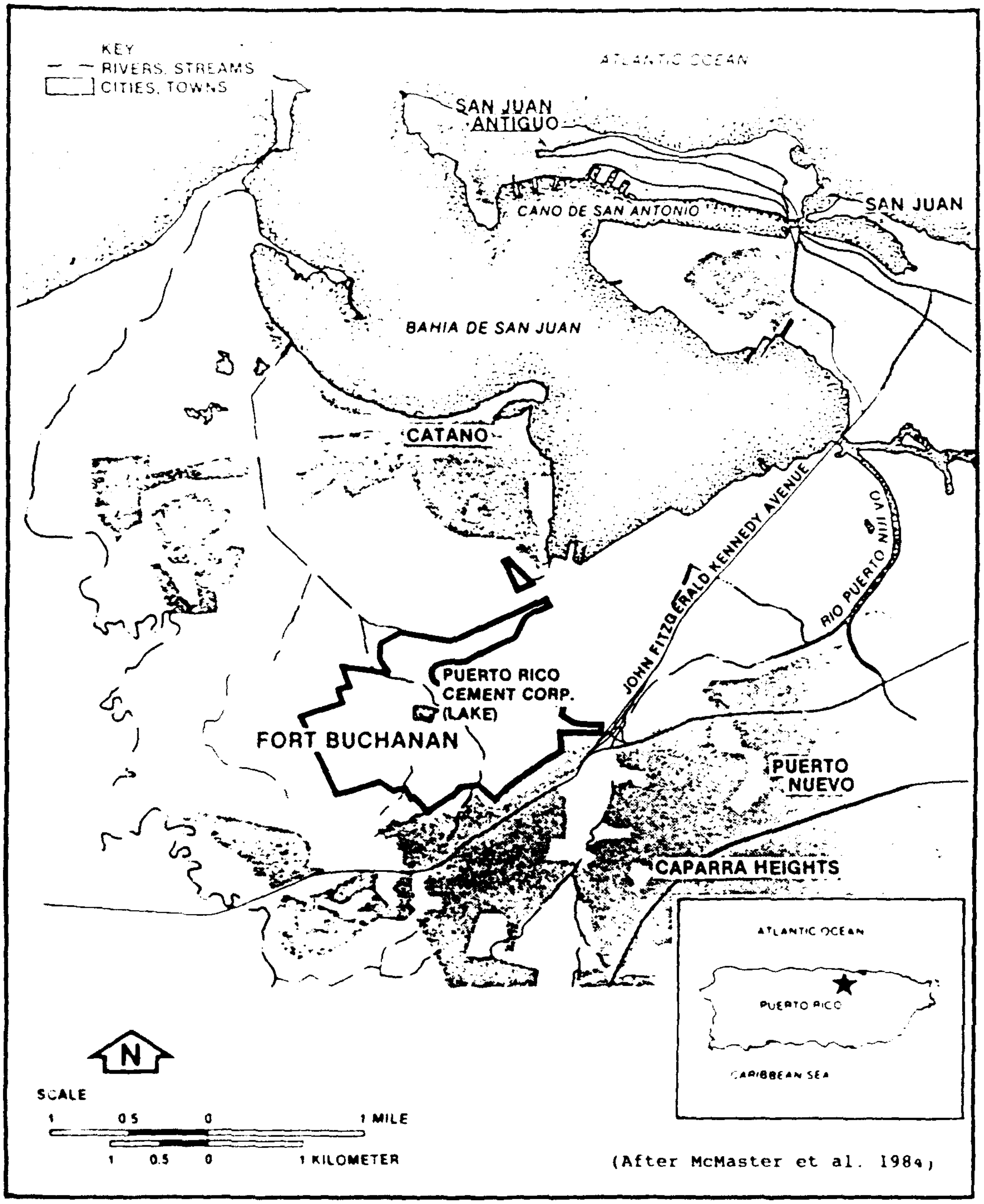


Figure 1. Vicinity map

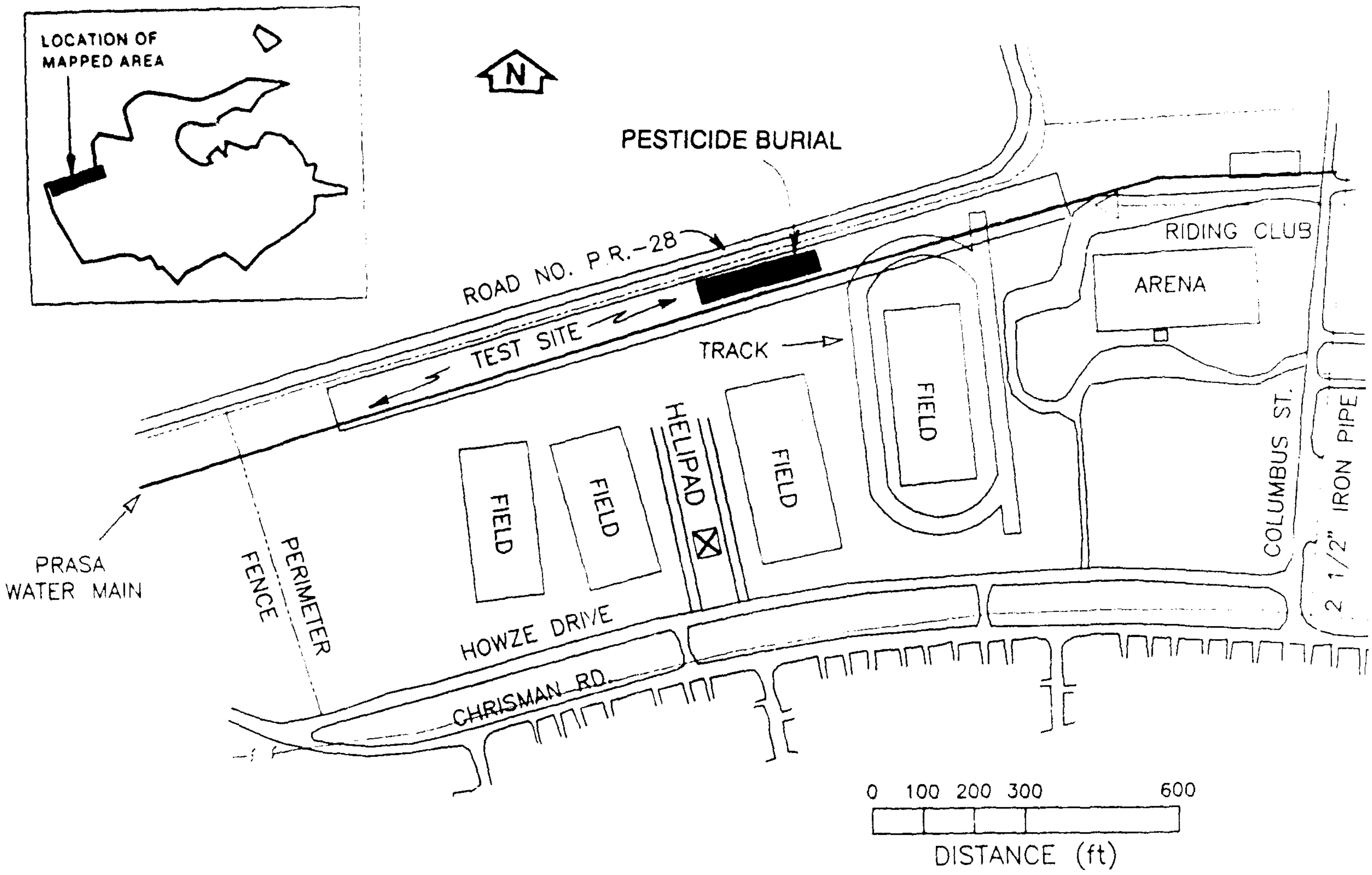


Figure 2. Pesticide burial trench location

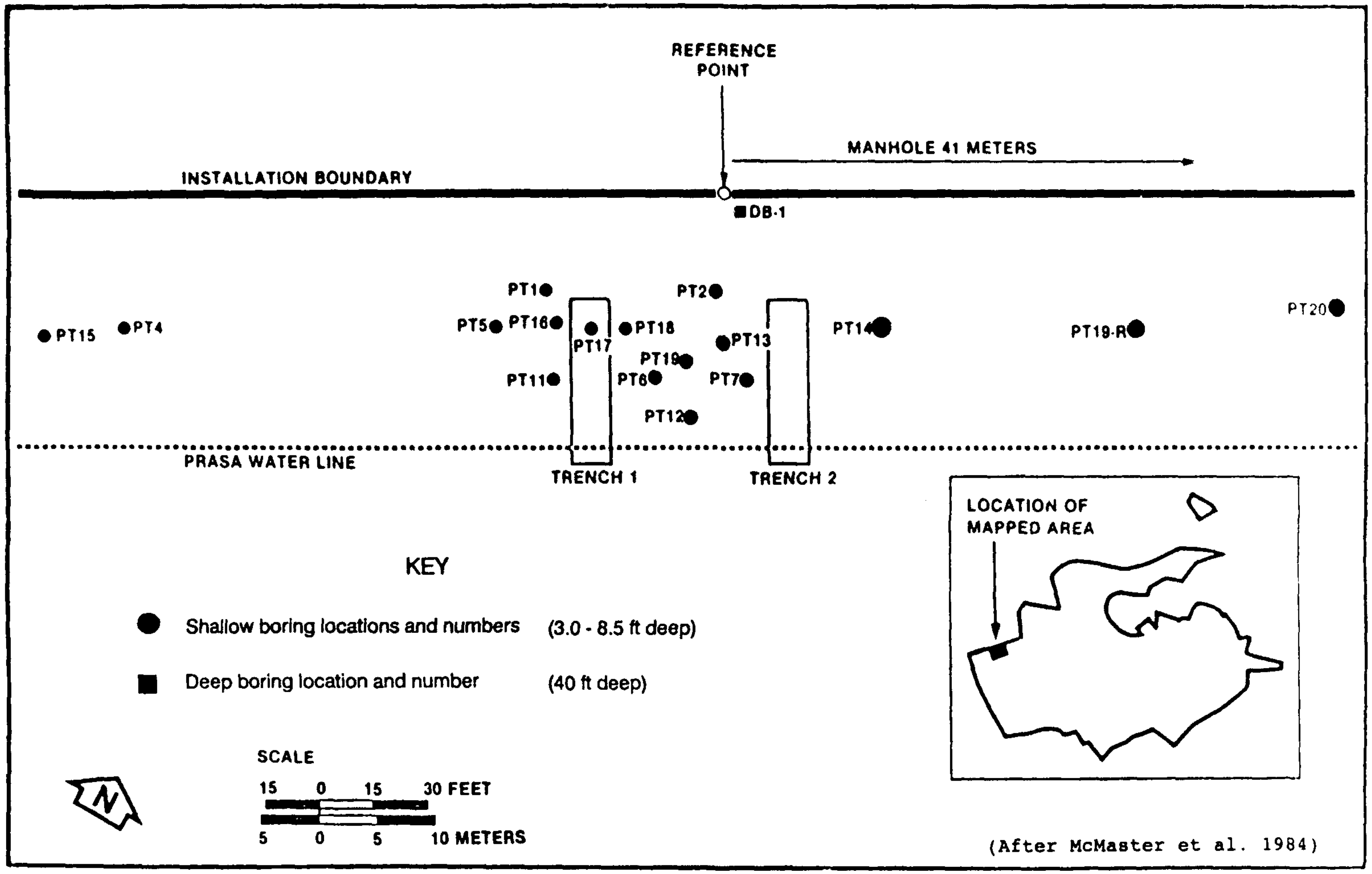


Figure 3. Location of 1983 soil borings

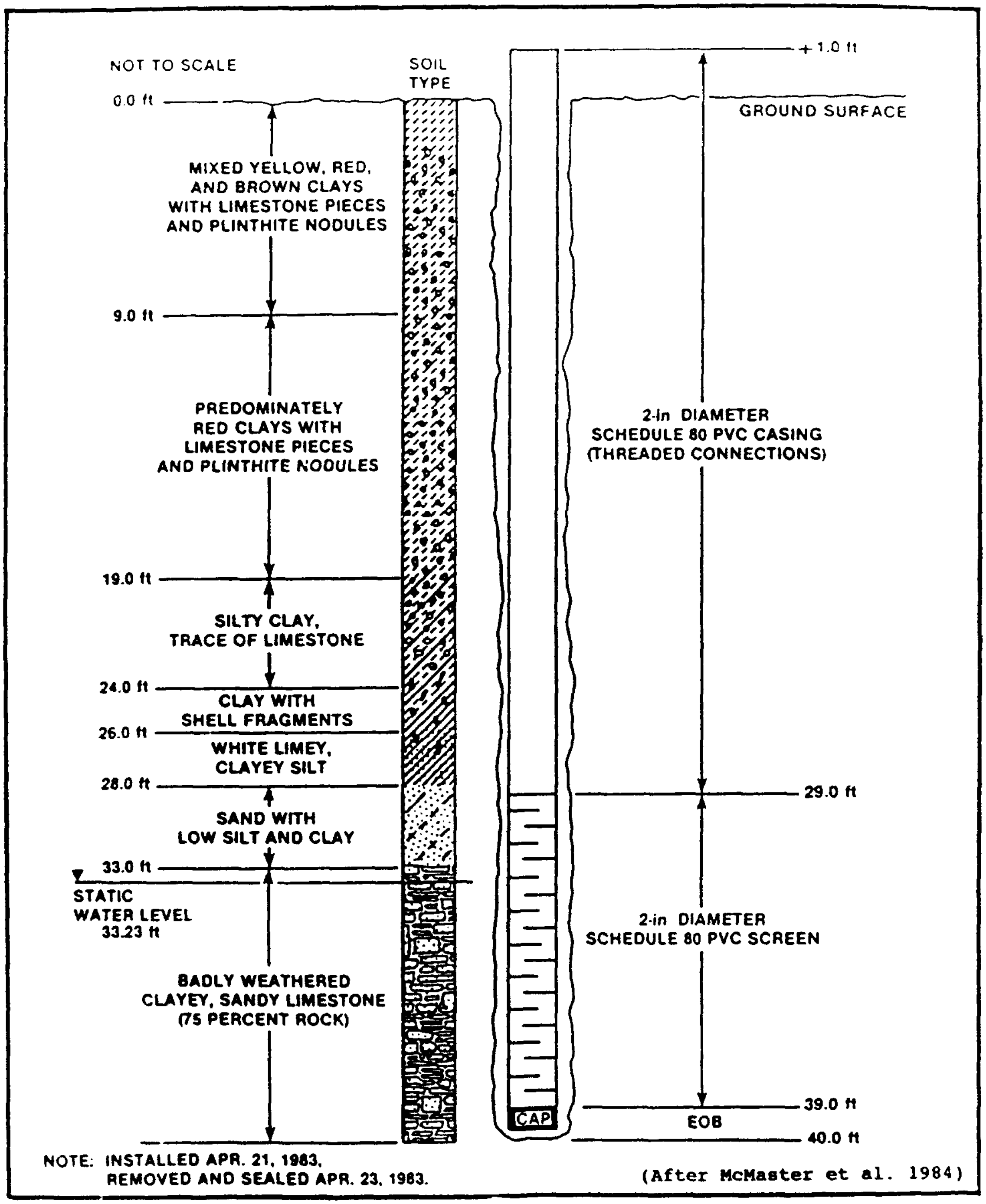


Figure 4. Log of deep soil boring DB-1

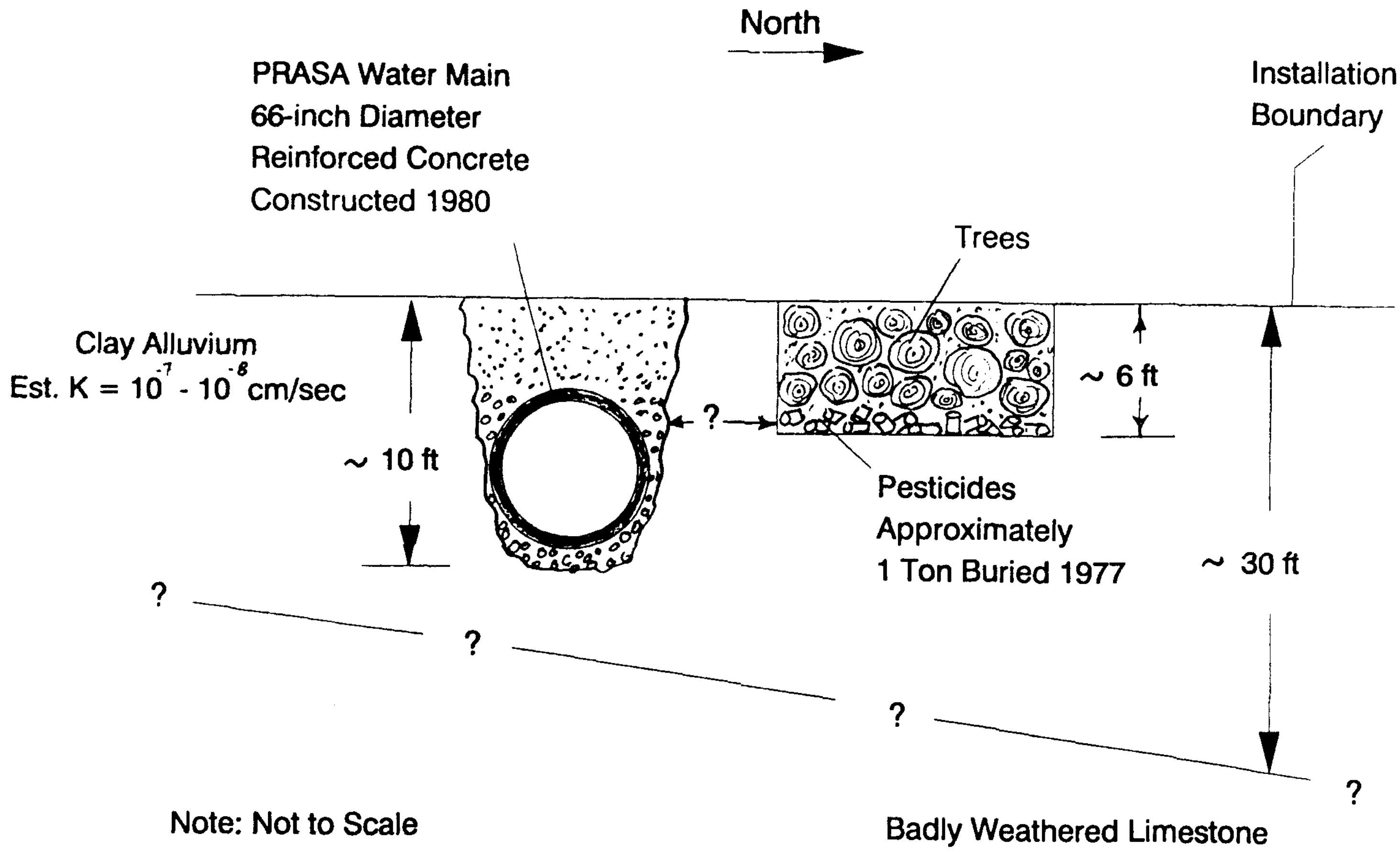


Figure 5. Schematic cross section of pesticide burial area

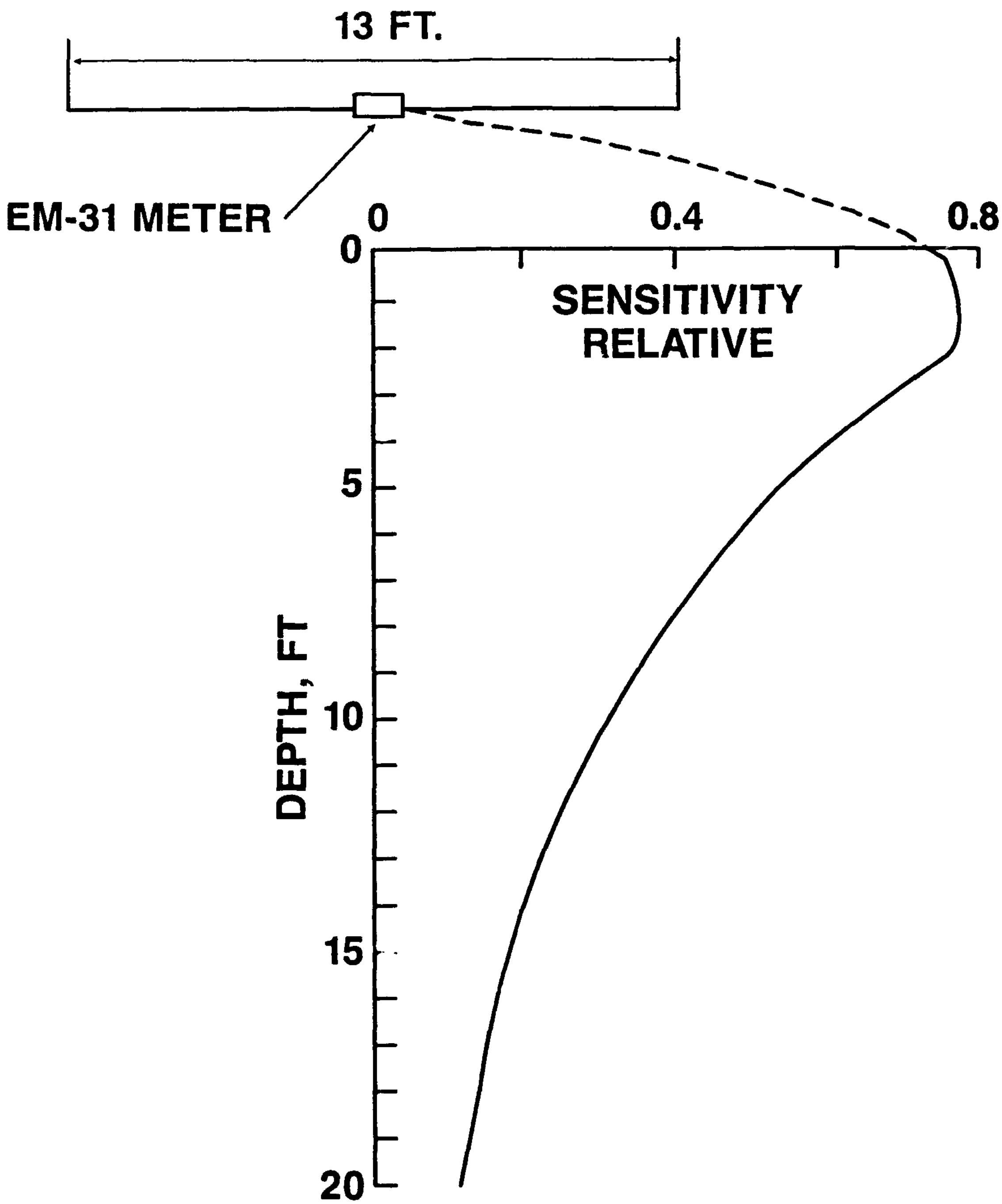


Figure 6. Sensitivity versus depth for the EM-31 terrain conductivity meter

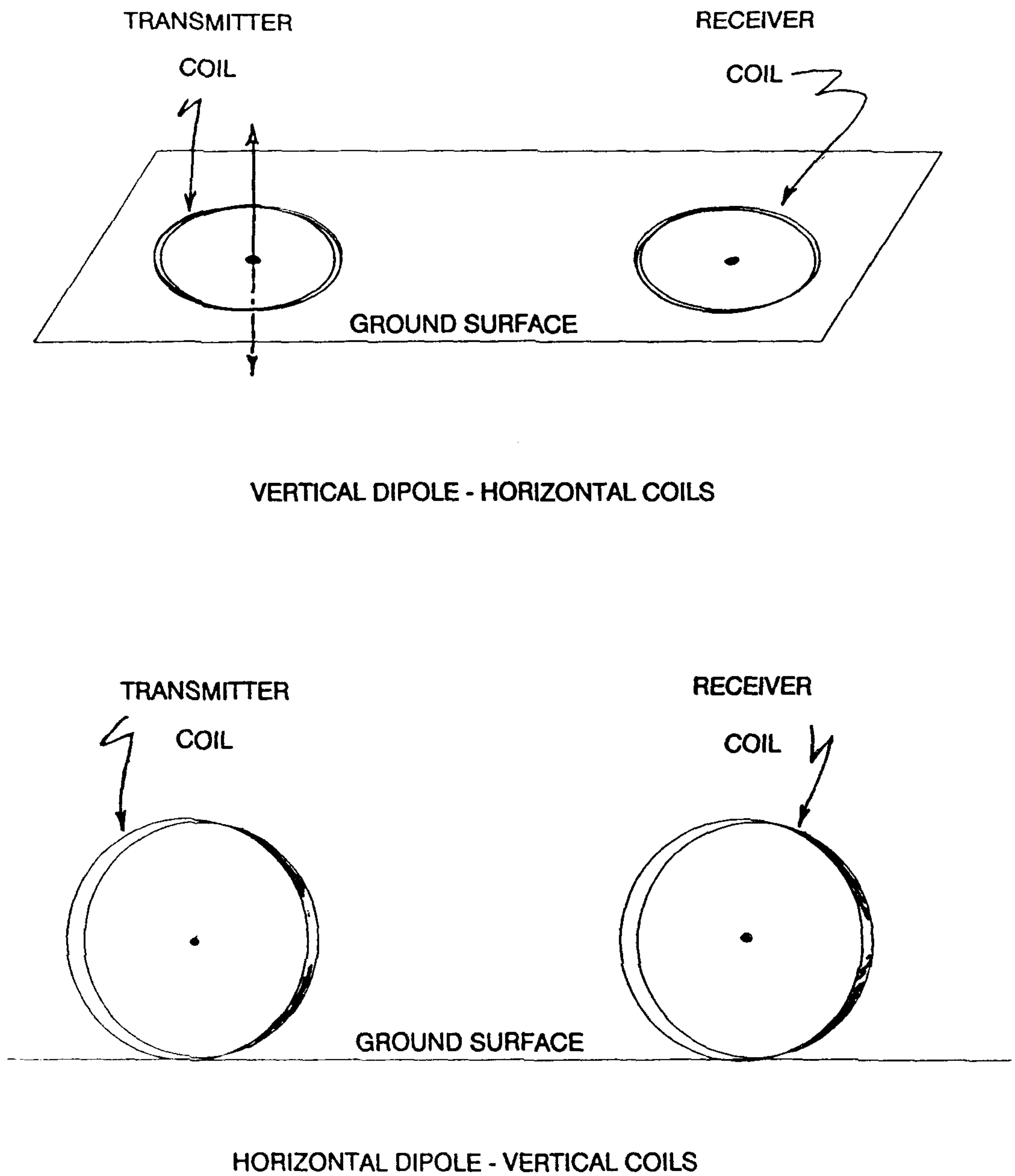


Figure 7. Schematic illustration of the EM-31 transmitter and receiver coil orientations

Figure 8. Geonics EM-31 terrain conductivity meter

Figure 9. EDA OMNI-IV proton-precession magnetometer

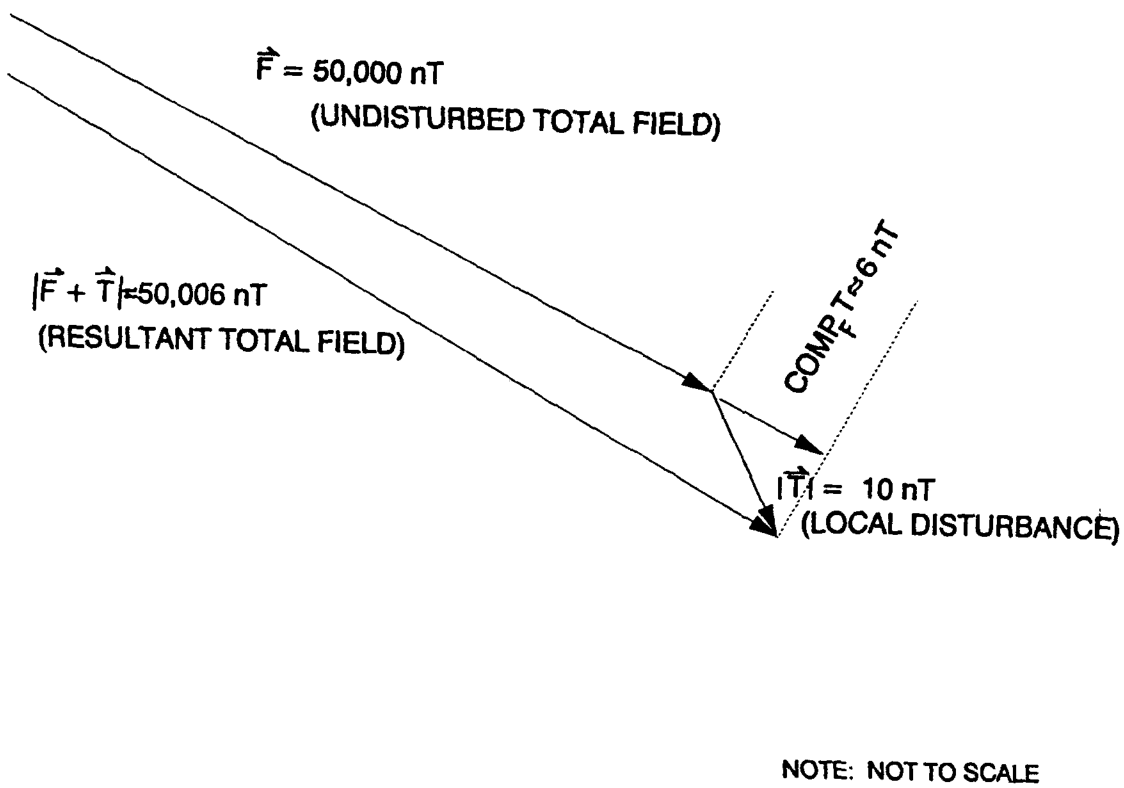


Figure 10. Local perturbation of the total field vector (after Breiner, 1973)

Figure 11. GSSI System 8 GPR

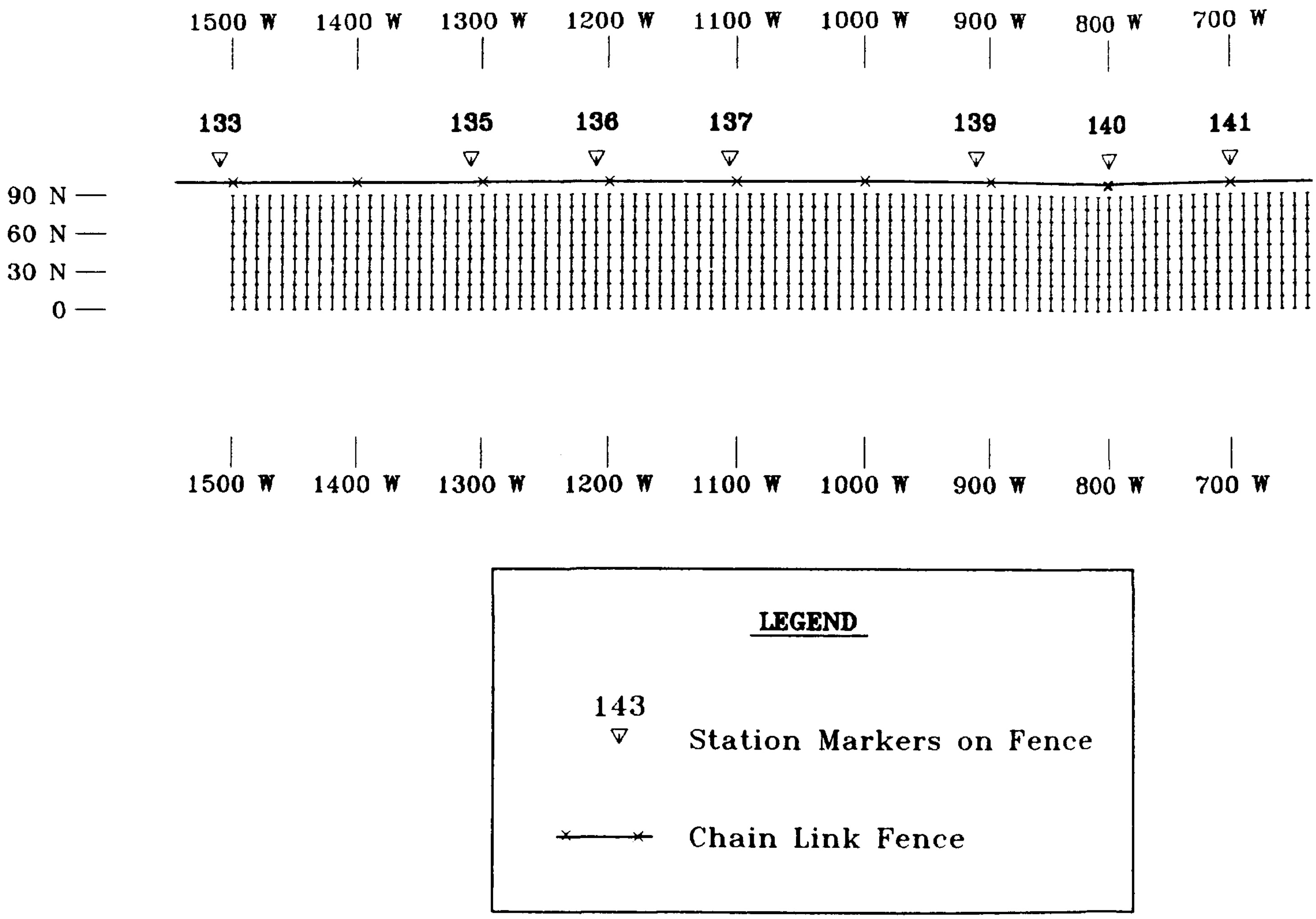
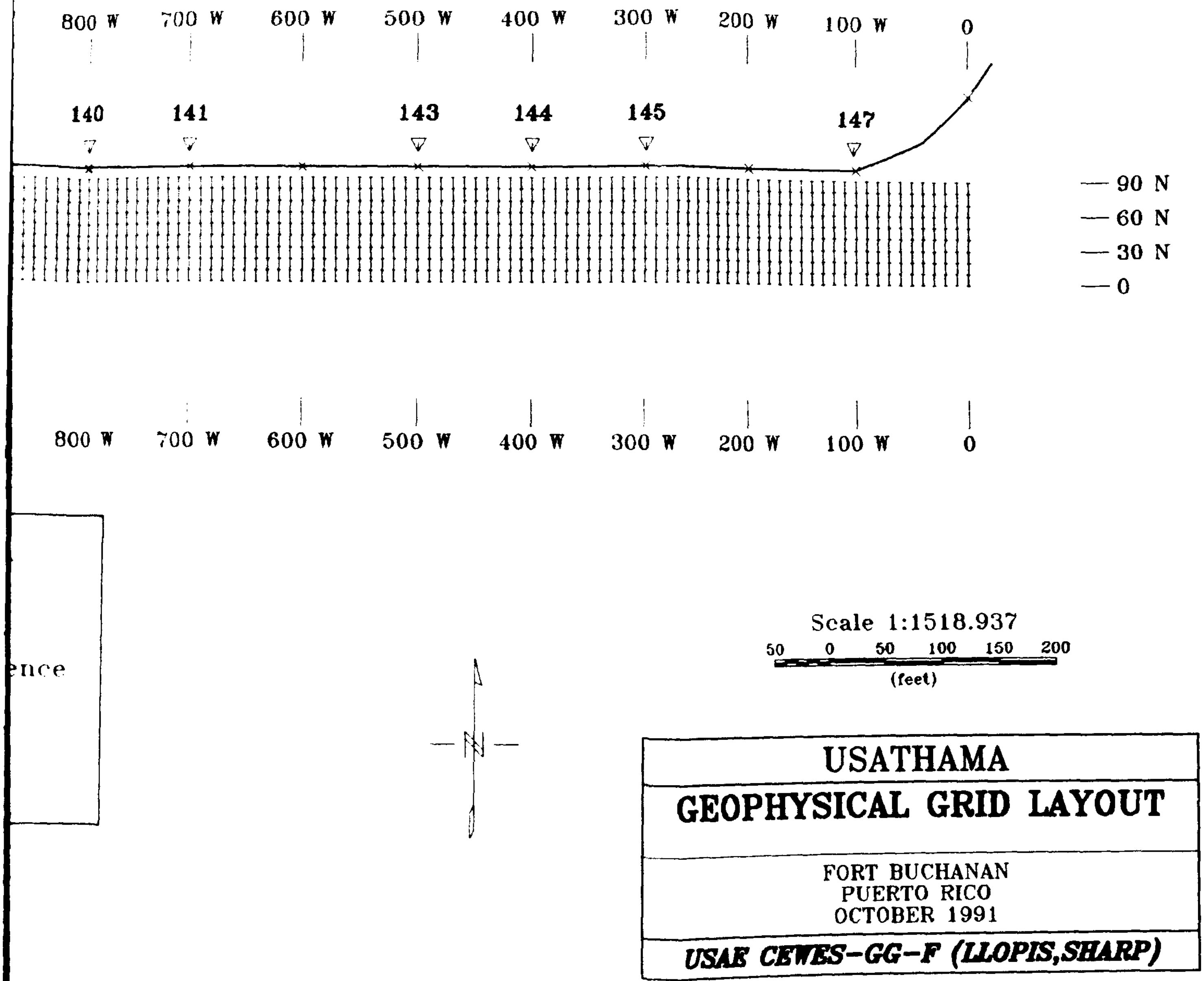


Figure 12. Geophysical surv



12. Geophysical survey grid

Figure 13. Digital data logger connected to an EM-31 conductivity meter

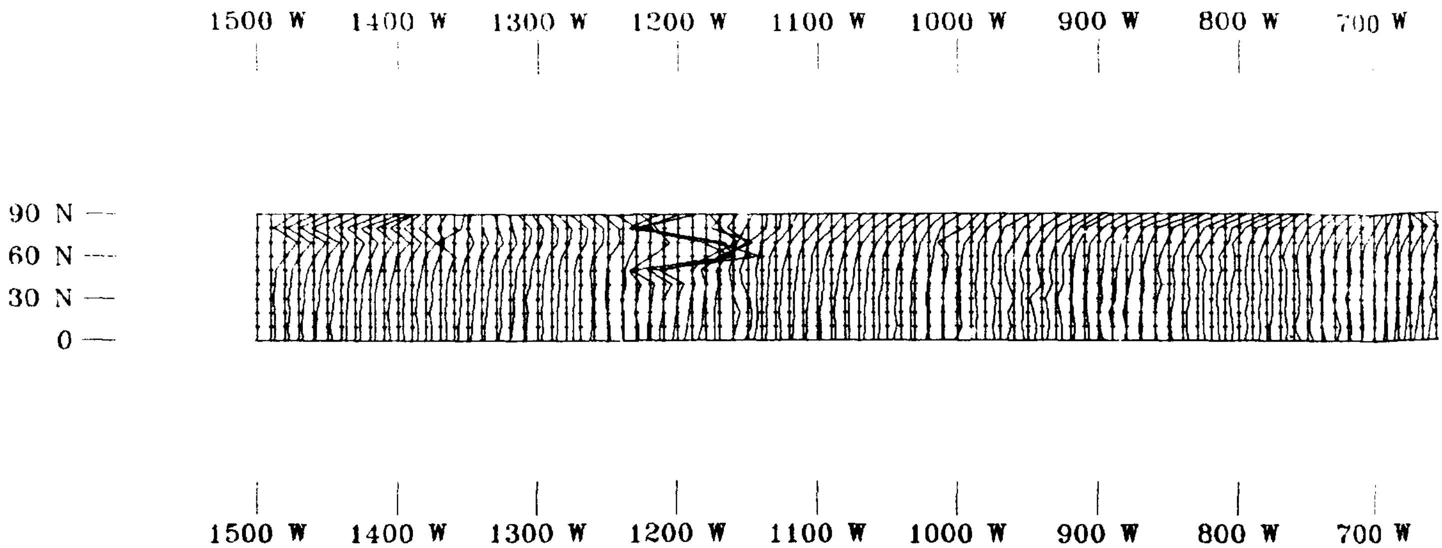
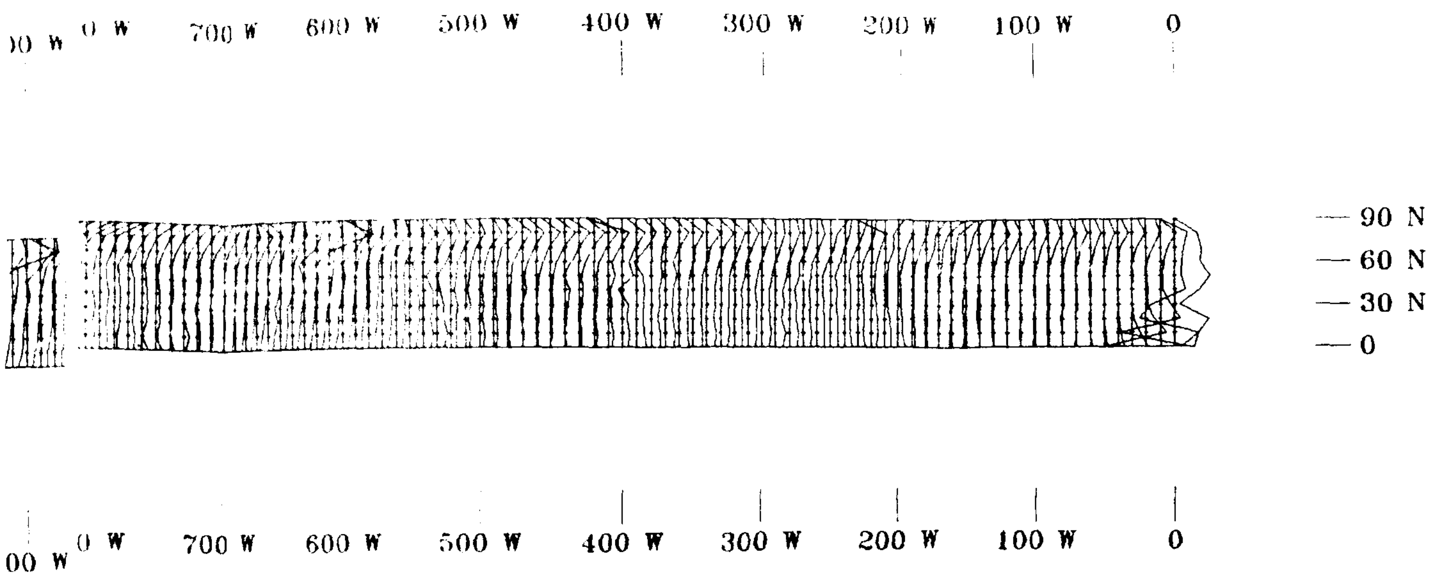


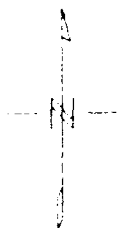
Figure 14. EM-31 quadrature phase test



Scale 1:1518.937

50 0 50 100 150 200

(feet)



USATHAMA
EM – 31 QUADRATURE PHASE **MILLISIEMENS PER METER (mS/m)**
FORT BUCHANAN PUERTO RICO OCTOBER 1991
USAE CEWES-GG-F (LLOPIS,SHARP)

:re phase test results, profile lines
sults

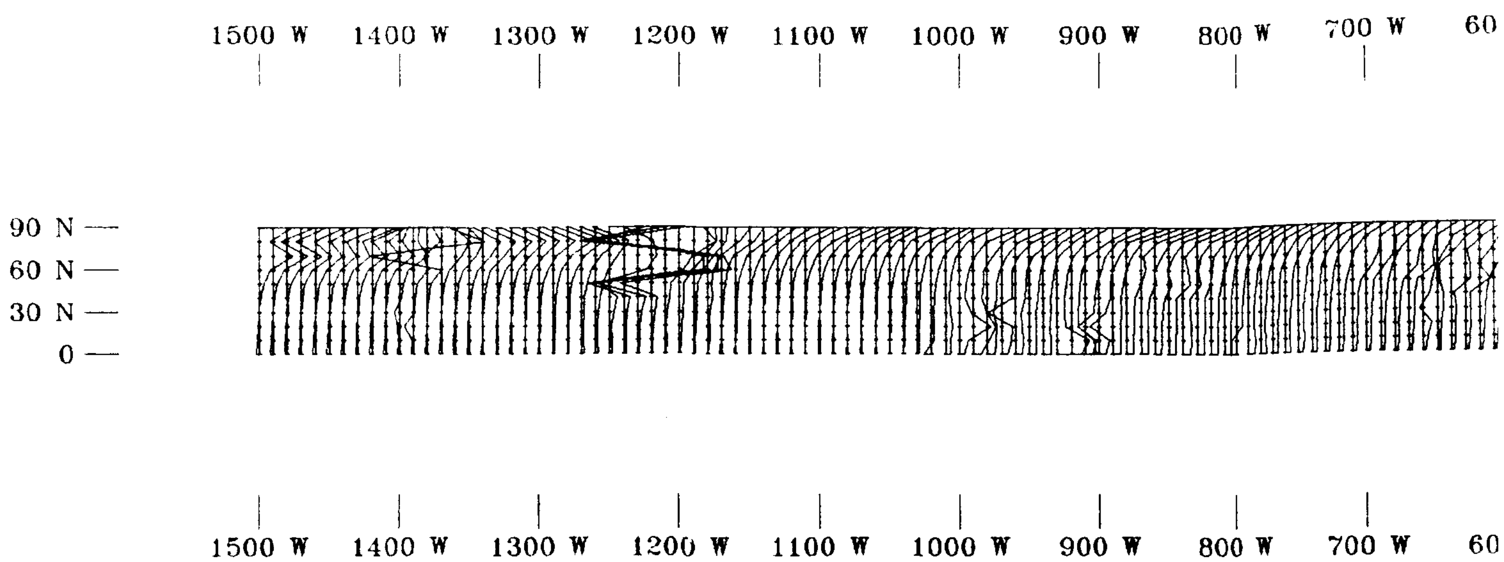
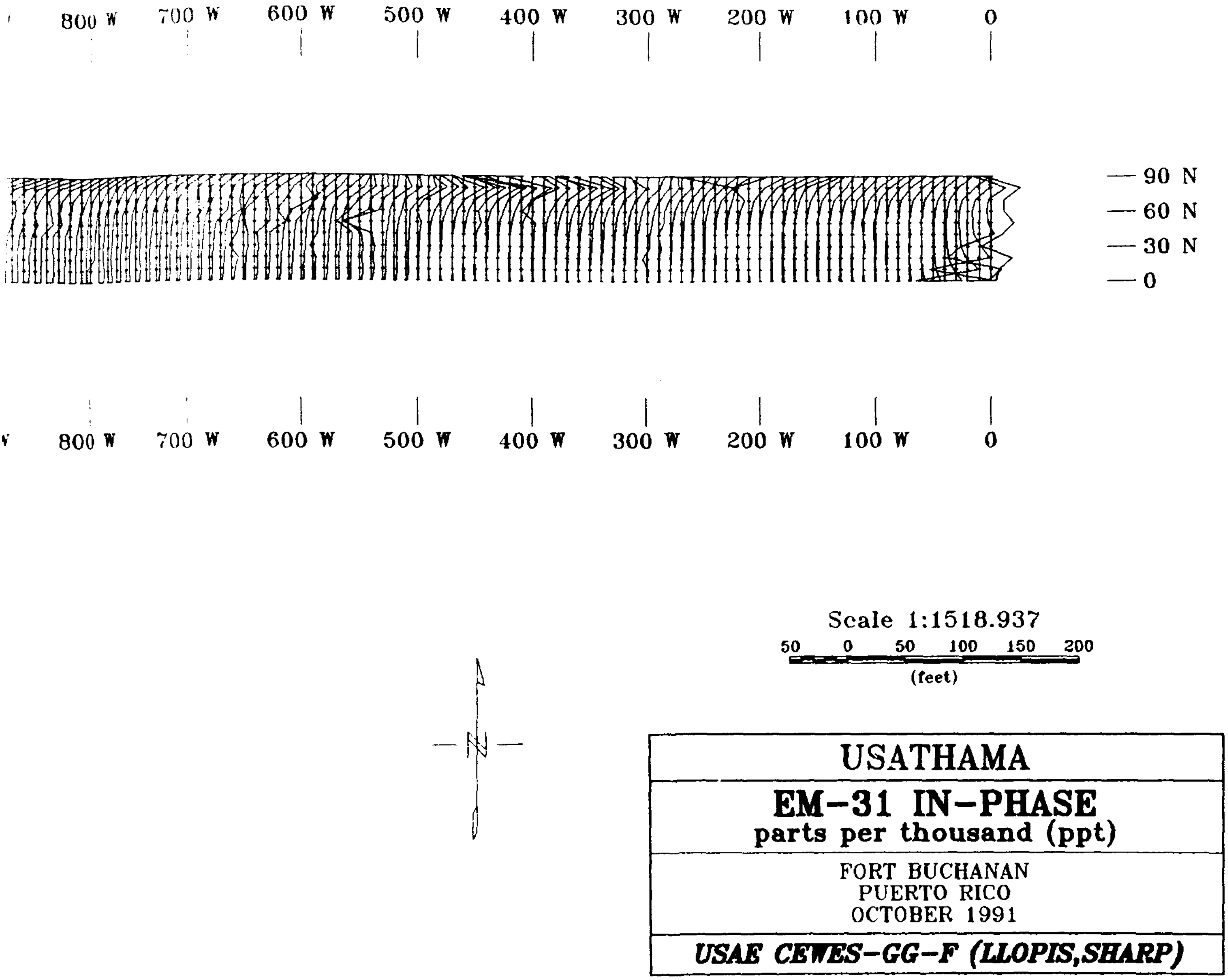


Figure 15. EM-31 in-phase test results



-31 in-phase test results, profile lines

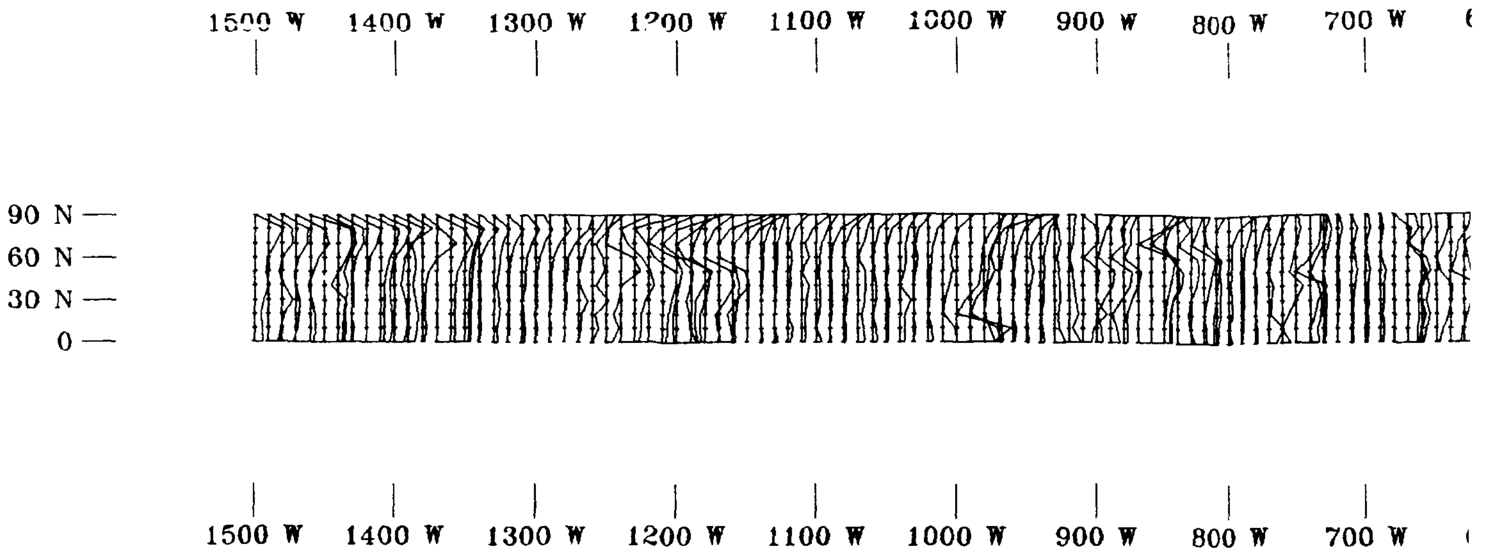
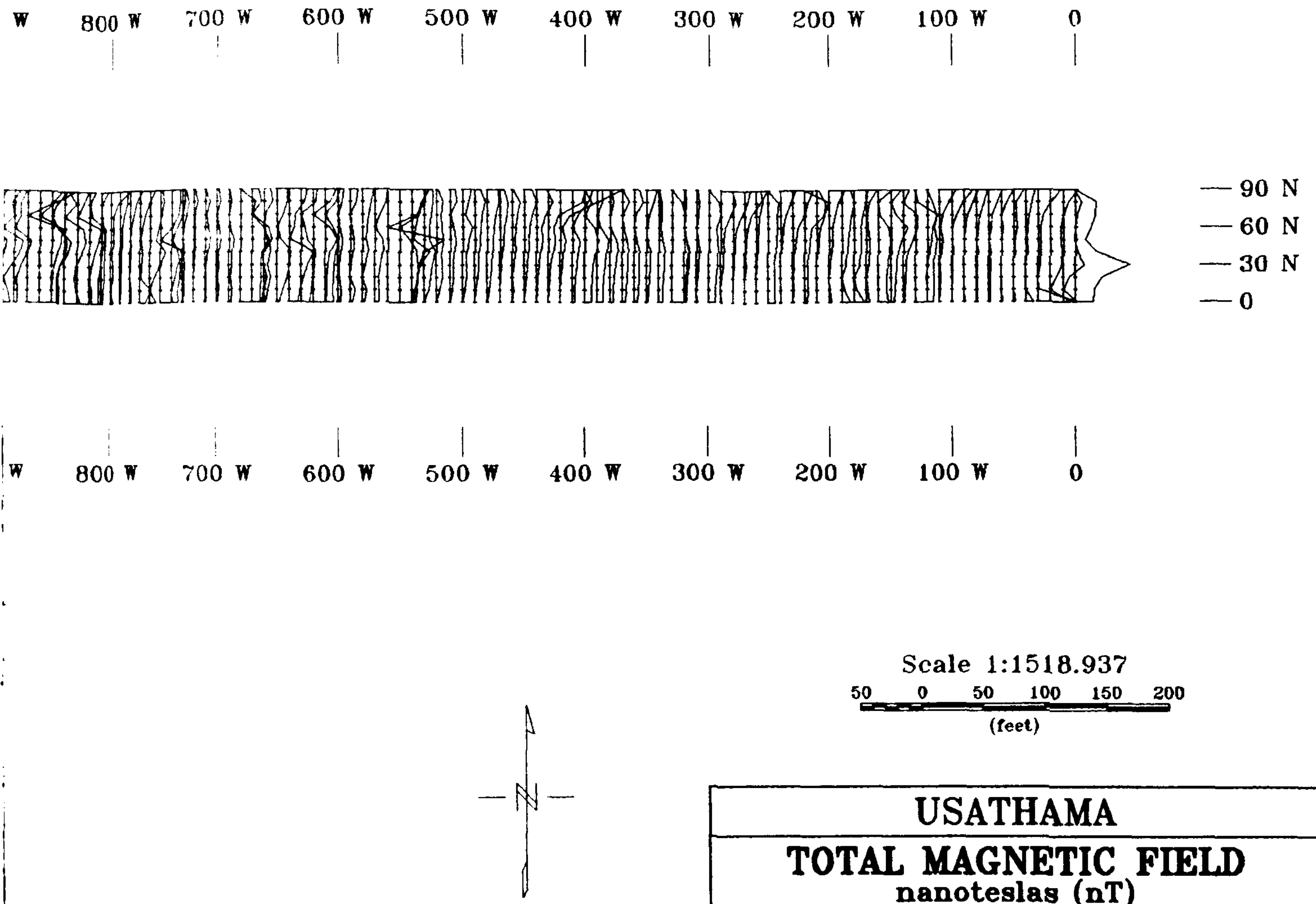


Figure 16. Total magnetic field test res



USATHAMA
TOTAL MAGNETIC FIELD **nanoteslas (nT)**
FORT BUCHANAN PUERTO RICO OCTOBER 1991
USAE CEWES-GG-F (LLOPIS,SHARP)

magnetic field test results, profile lines

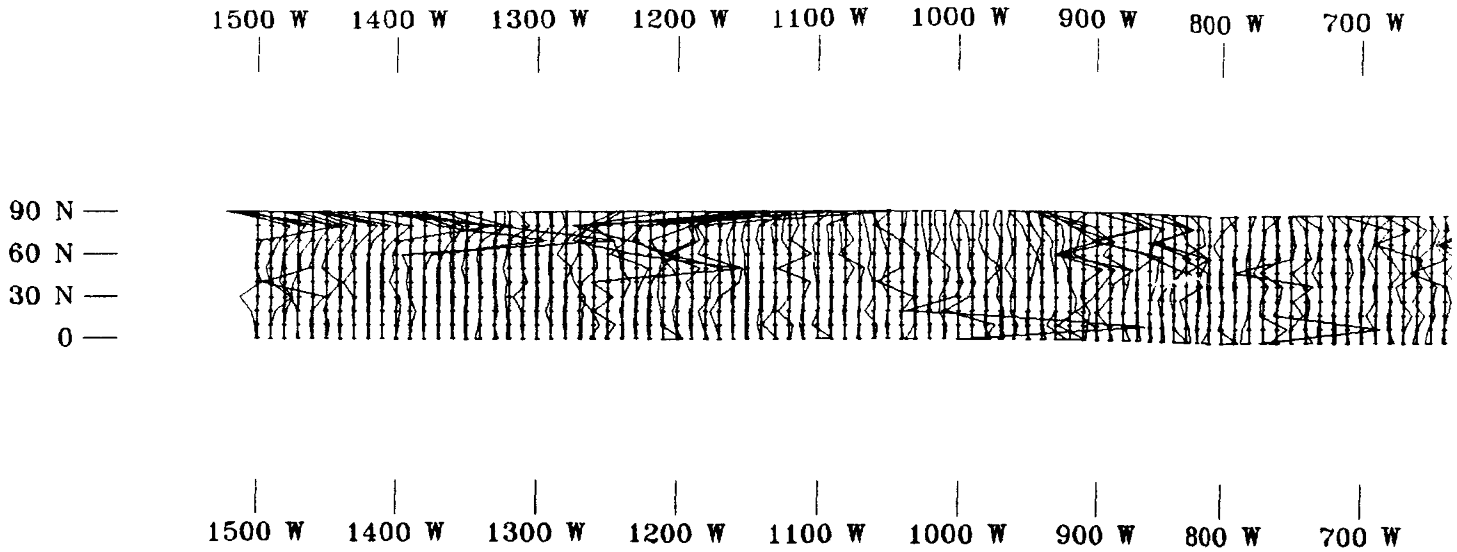
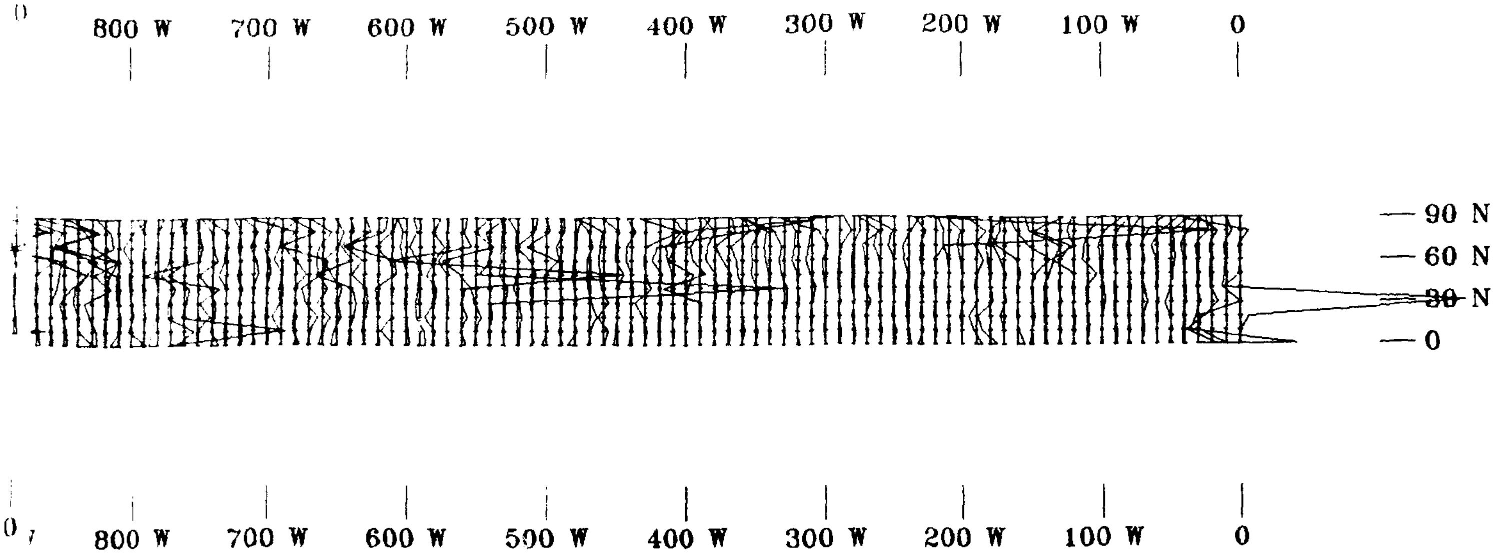


Figure 17. Magnetic gradient test resu



Scale 1:1518.937

50 0 50 100 150 200

(feet)

USATHAMA
MAGNETIC GRADIENT (nT/m)
FORT BUCHANAN PUERTO RICO OCTOBER 1991
USAE CEWES-GG-F (LLOPIS,SHARP)

netic gradient test results, profile lines

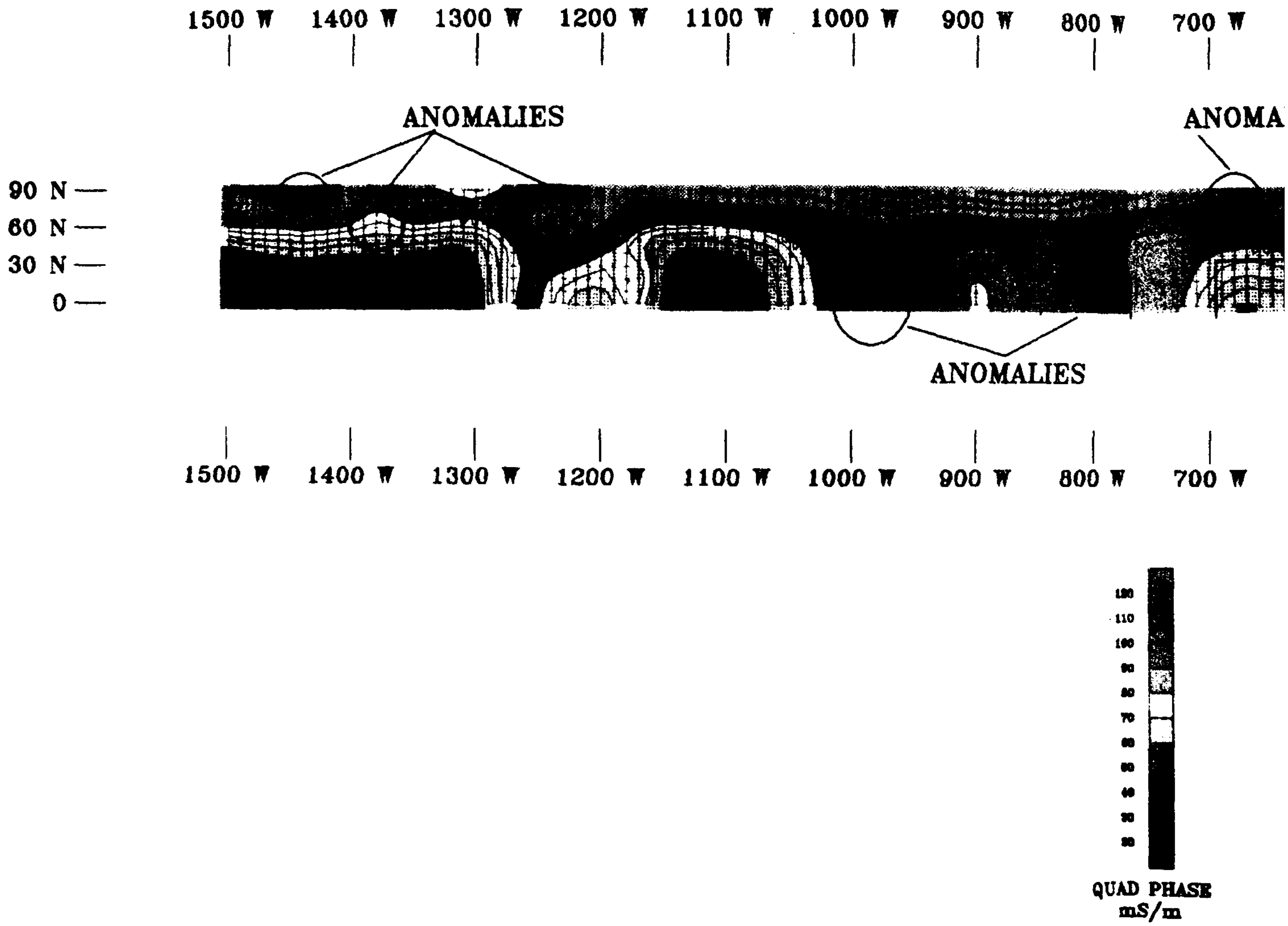
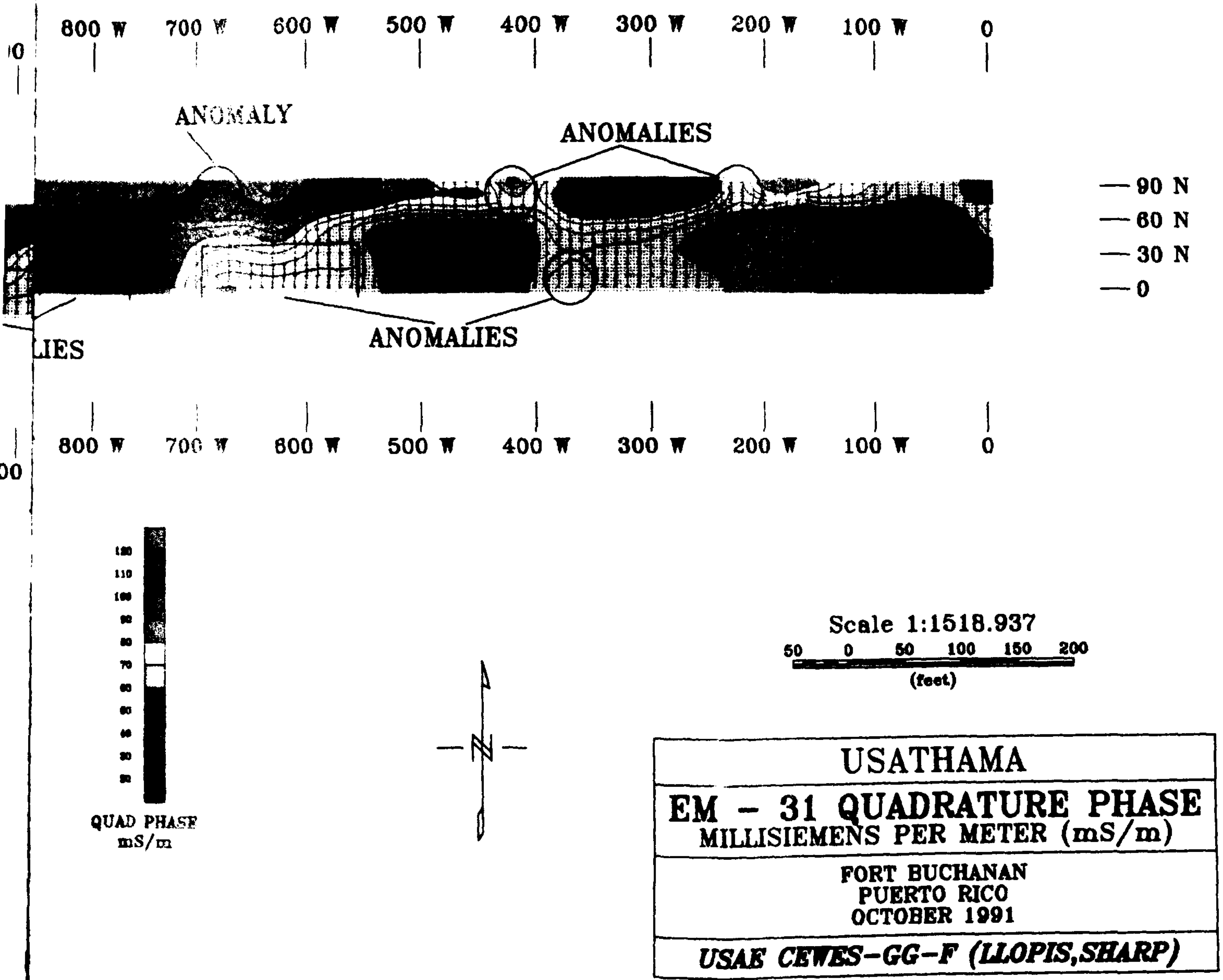


Figure 18. EM-31 quadrature p



EM-31 quadrature phase test results, contour plot

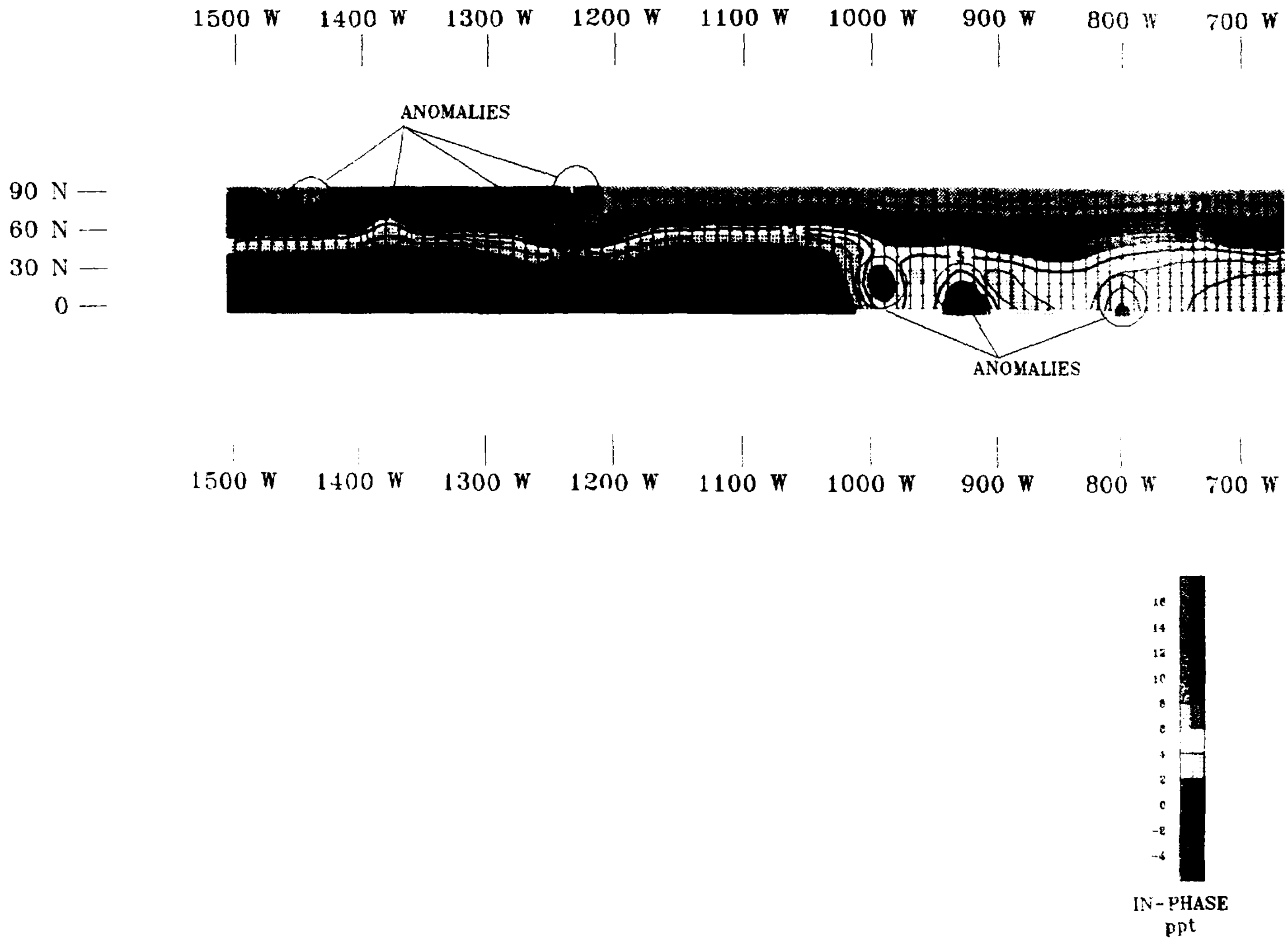
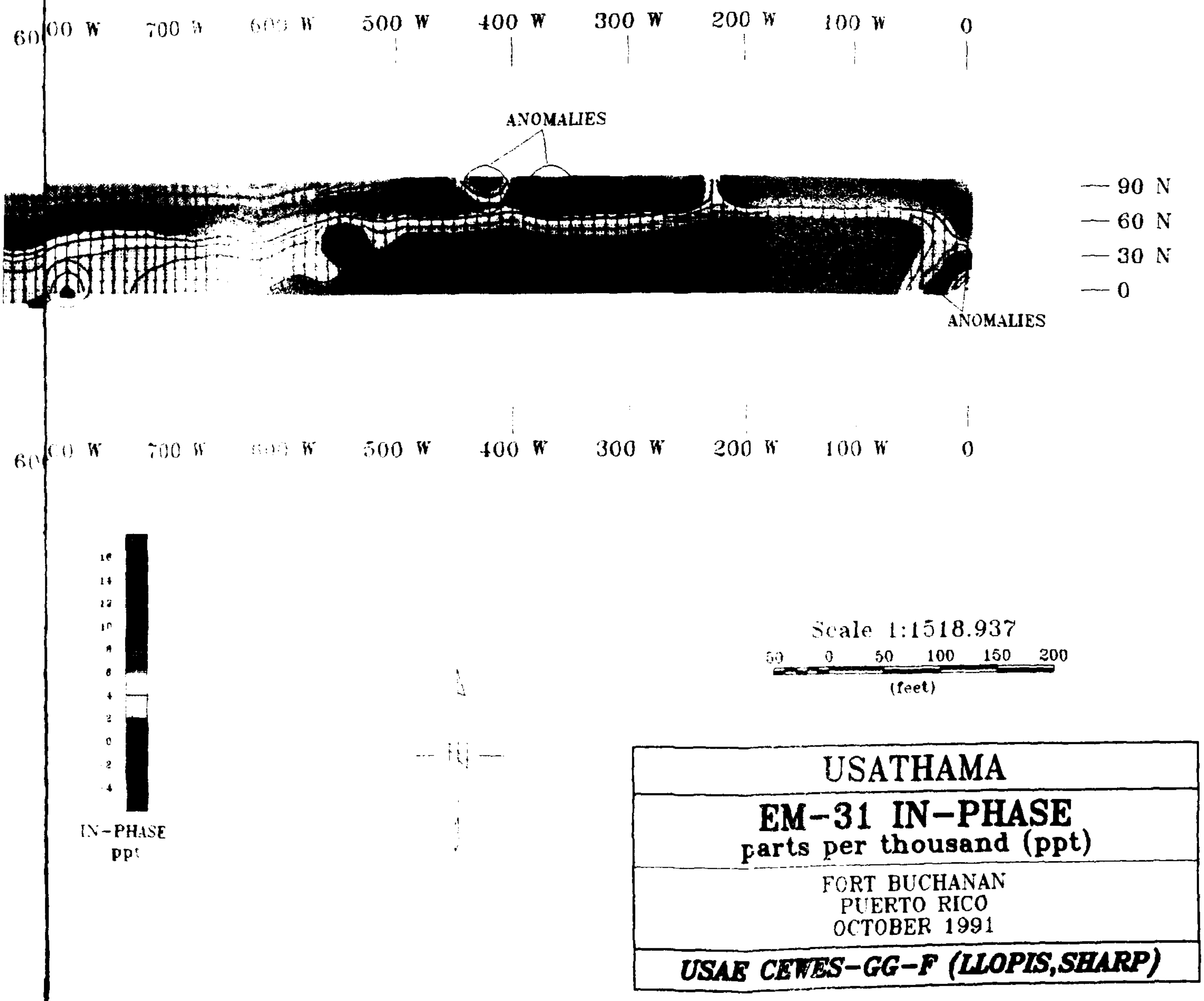


Figure 19. EM-31 in-phas



EM-31 in-phase test results, contour plot

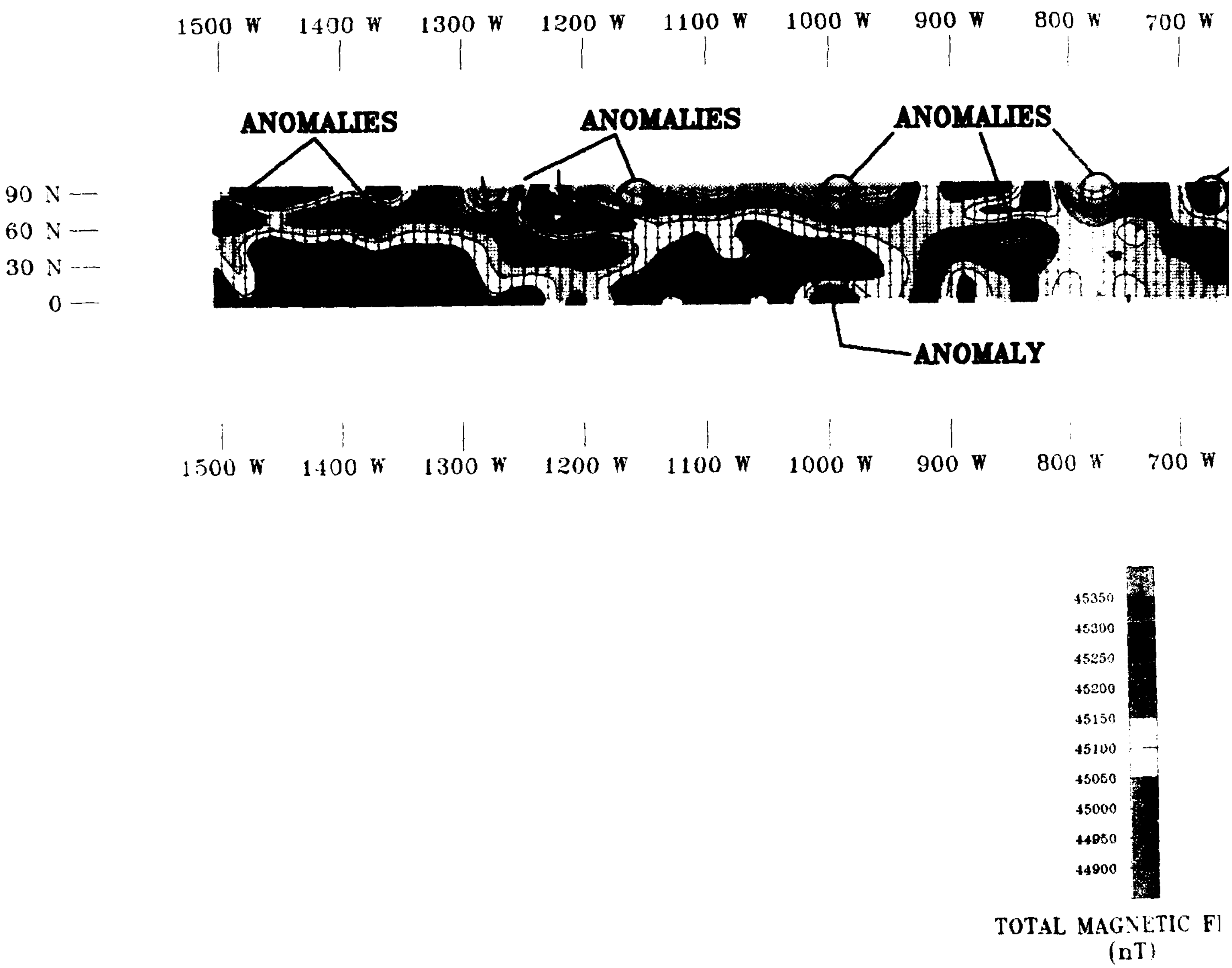
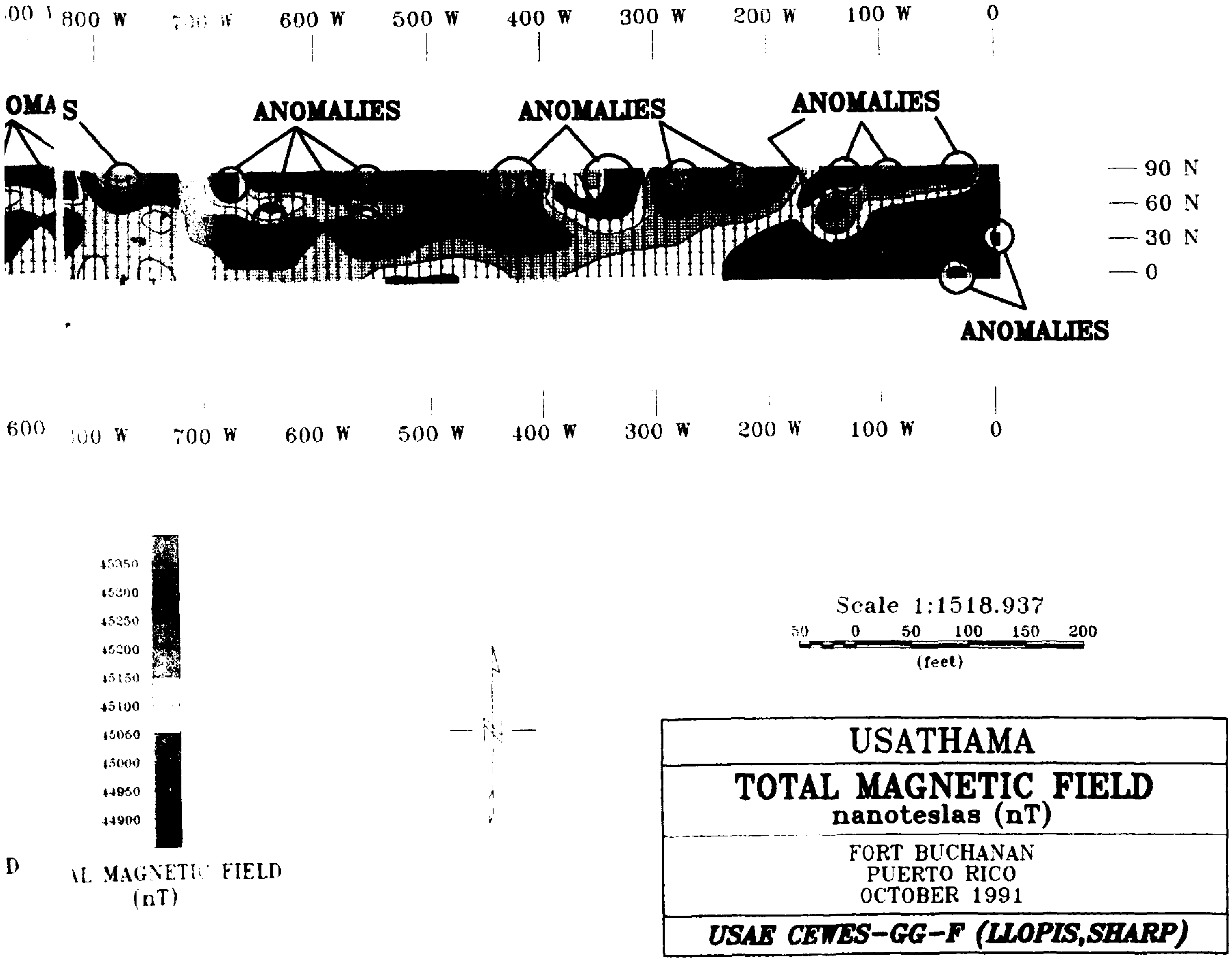


Figure 20. Total magnetic fiel



est 1 magnetic field test results, contour plot

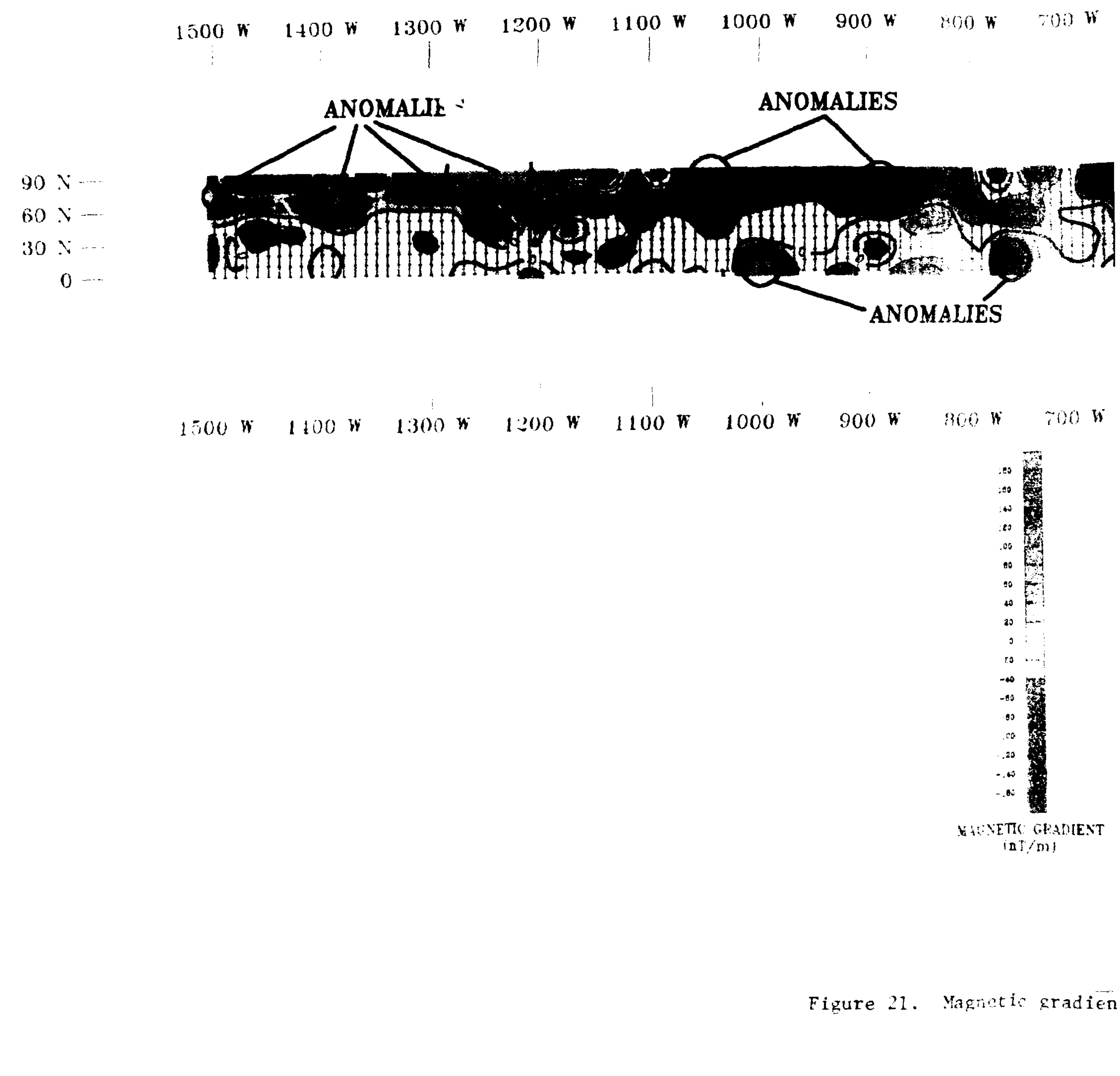
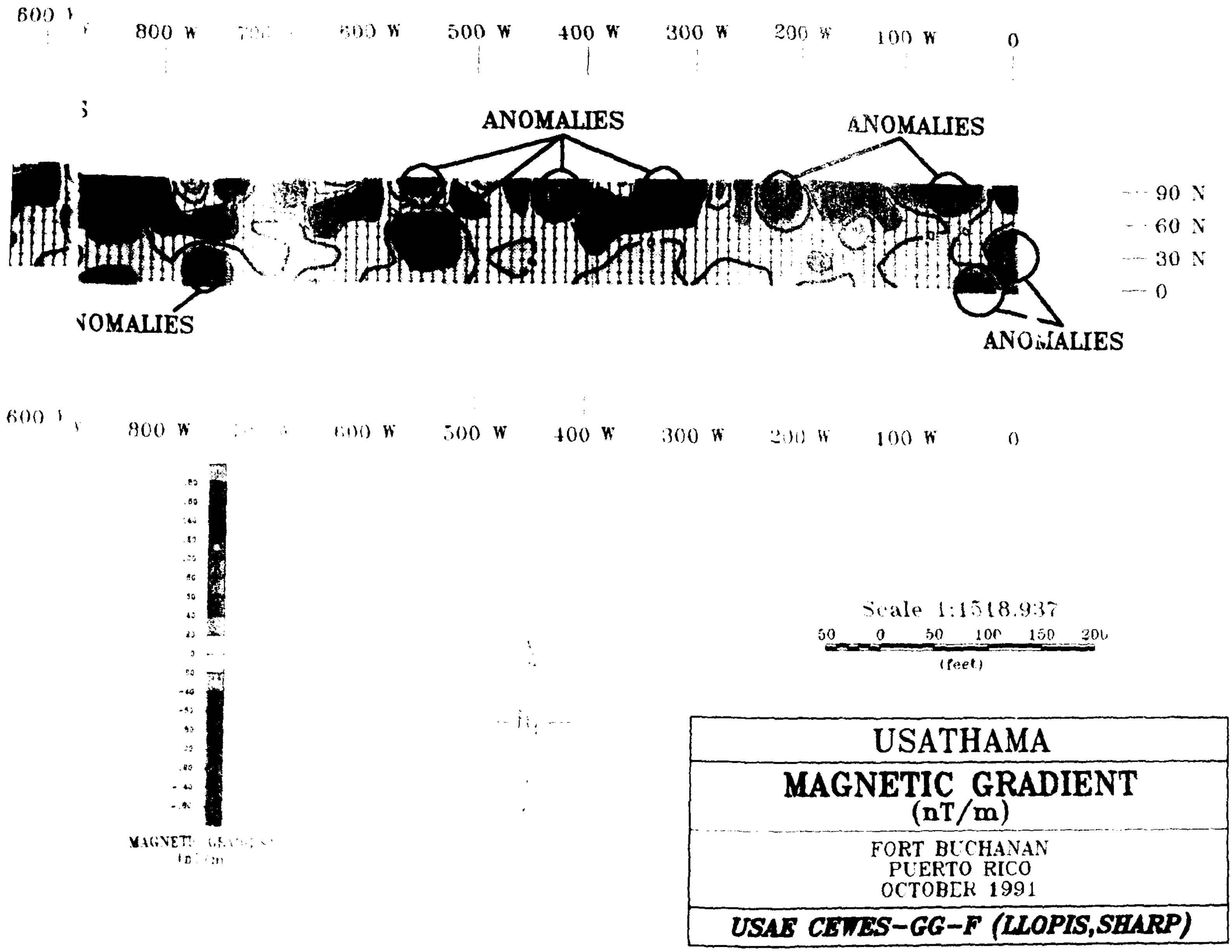


Figure 21. Magnetic gradient



st re . Magneti test results, contour plot

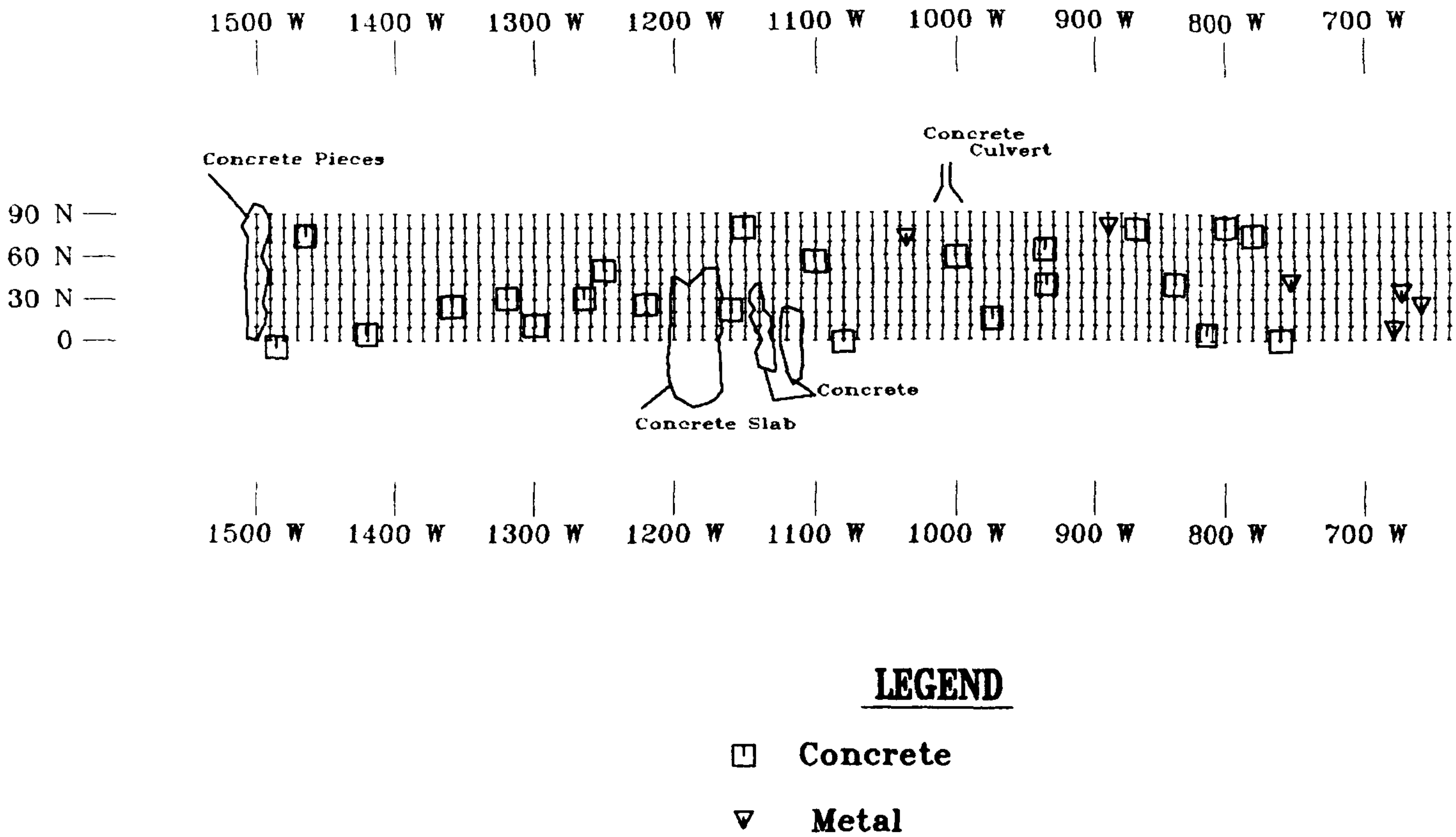
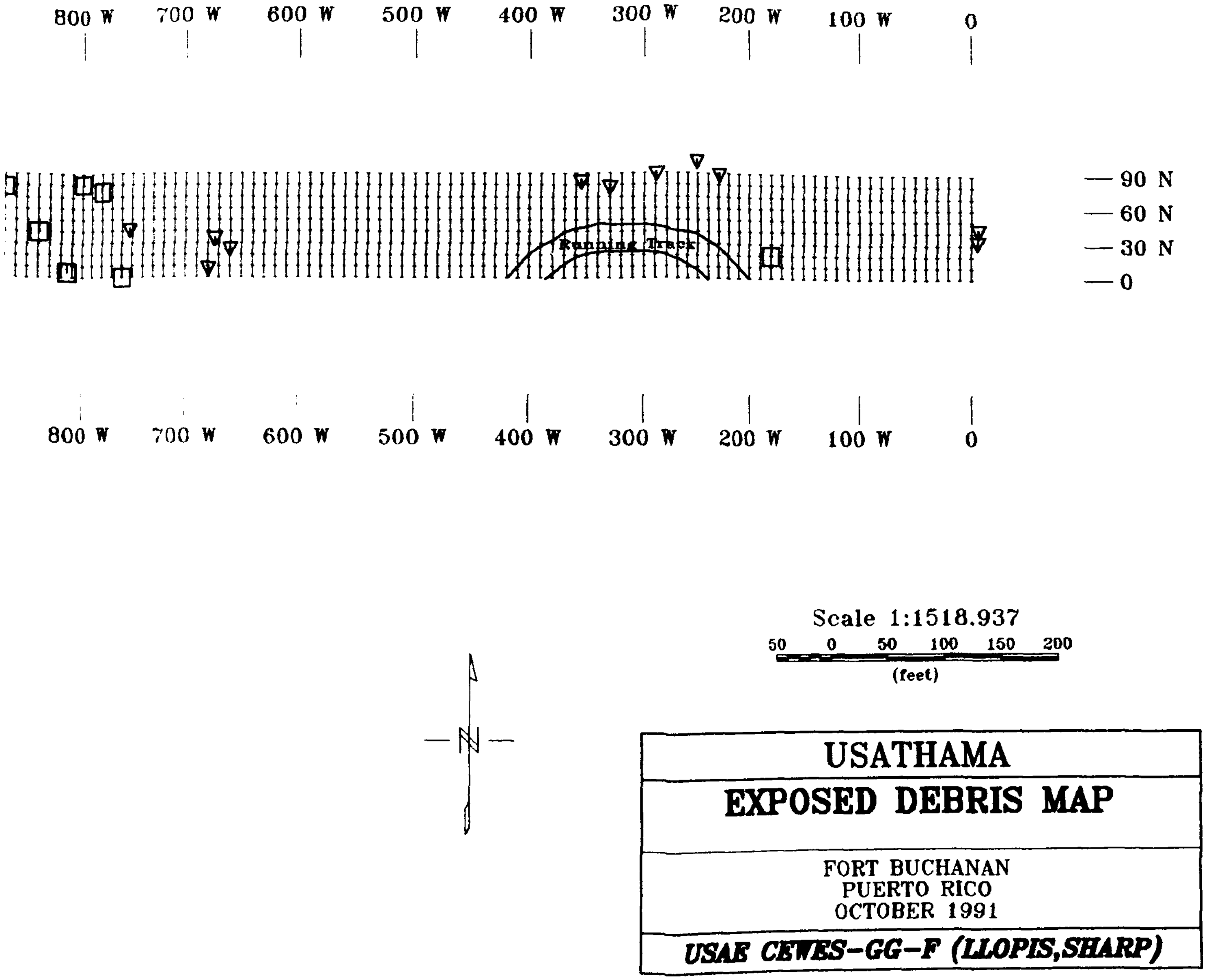
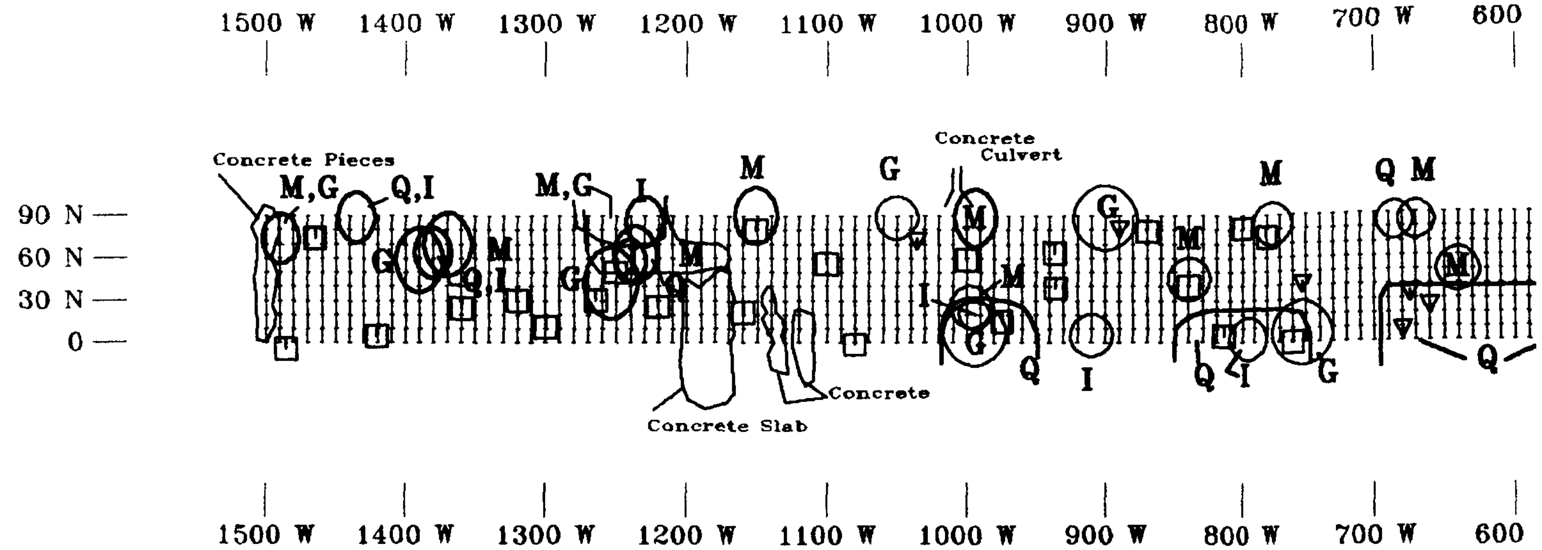


Figure 22. Exposed debri



re 22. Exposed debris map



LEGEND

□ Concrete

▽ Metal

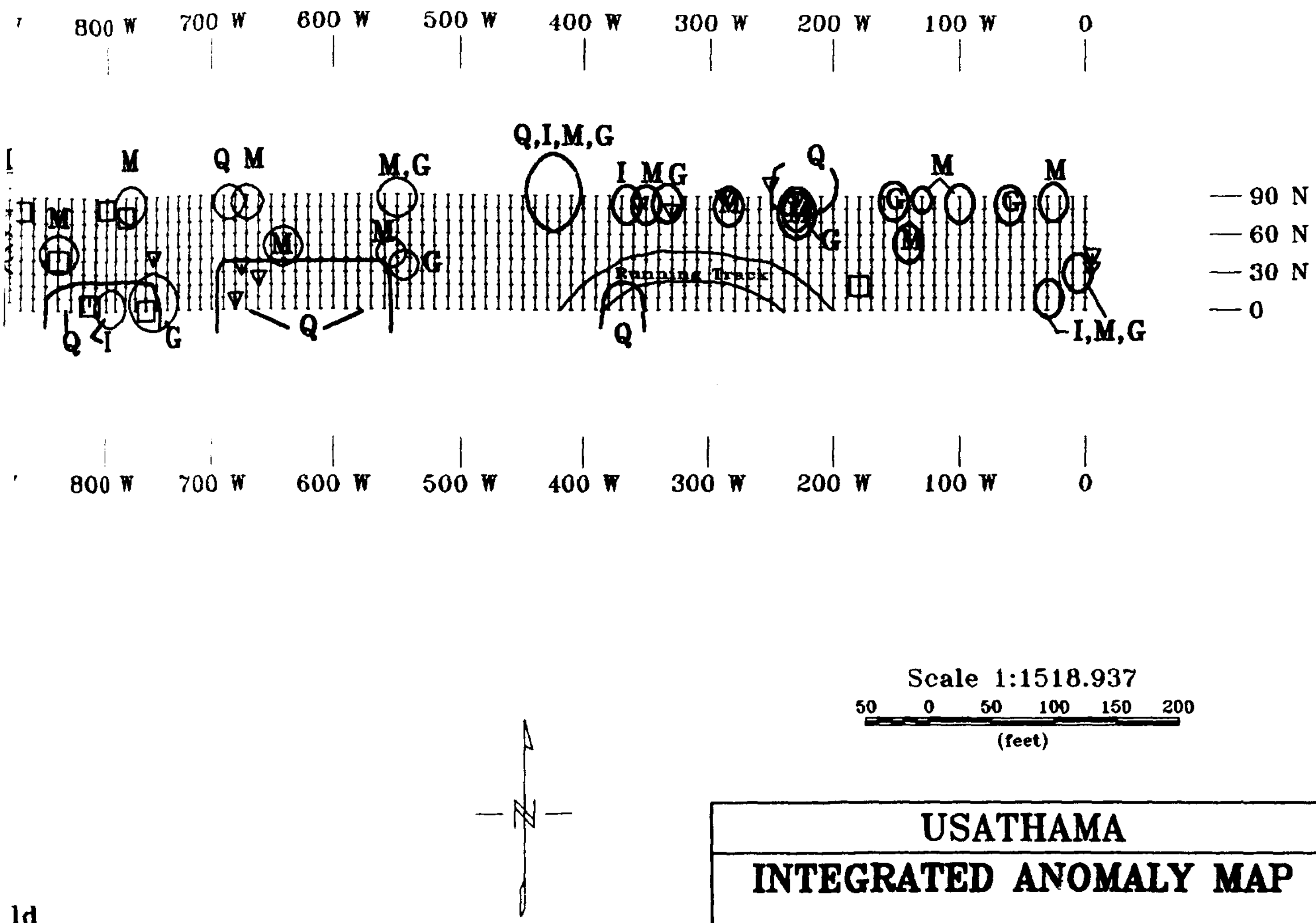
Q EM Quad Phase

I EM In Phase

M Total Magnetic Field

G Magnetic Gradient

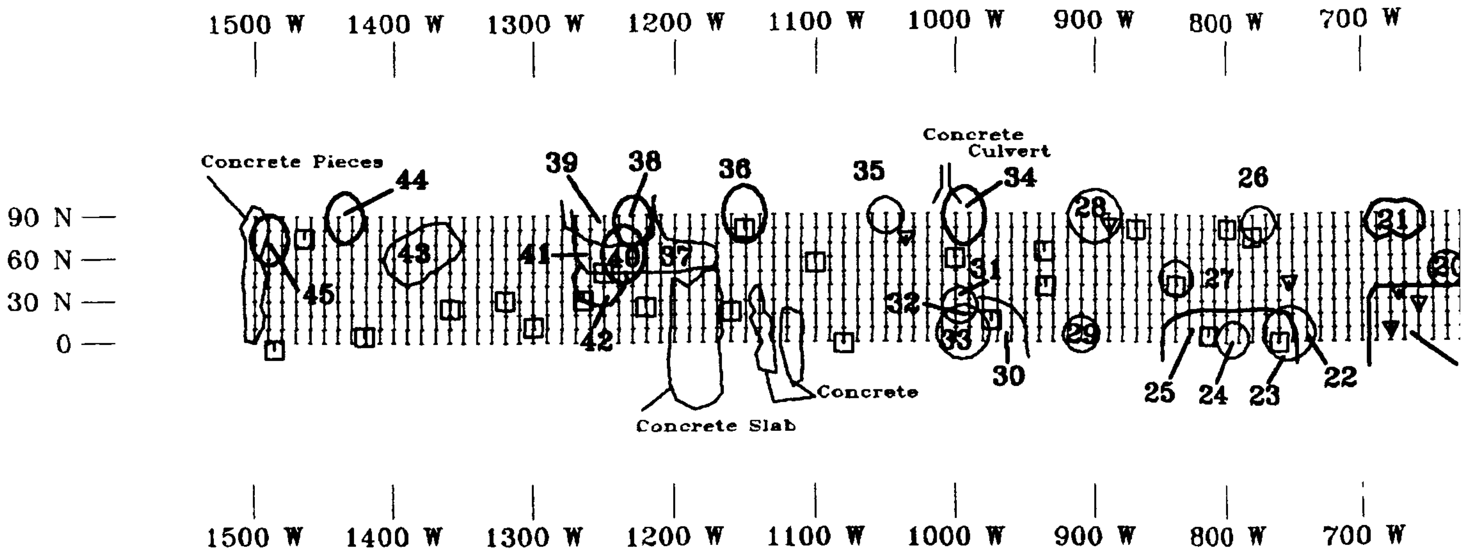
Figure 23. Integrated anomaly



USATHAMA
INTEGRATED ANOMALY MAP
FORT BUCHANAN PUERTO RICO OCTOBER 1991
USAE CEWES-GG-F (LLOPIS,SHARP)

ld

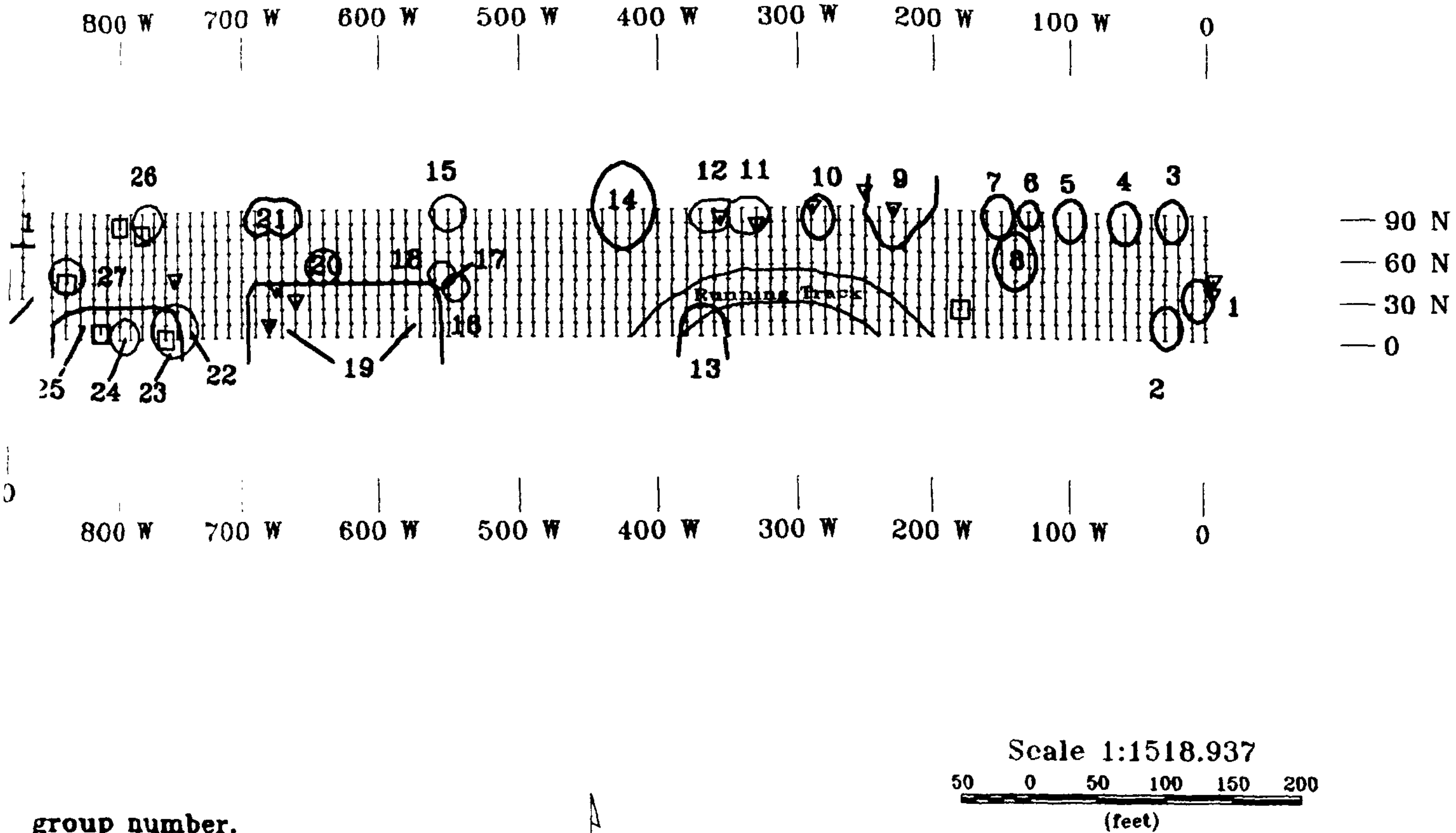
e 23. Integrated anomaly map



Values refer to anomaly group number.

Please refer to text.

Figure 24. Anomaly grou



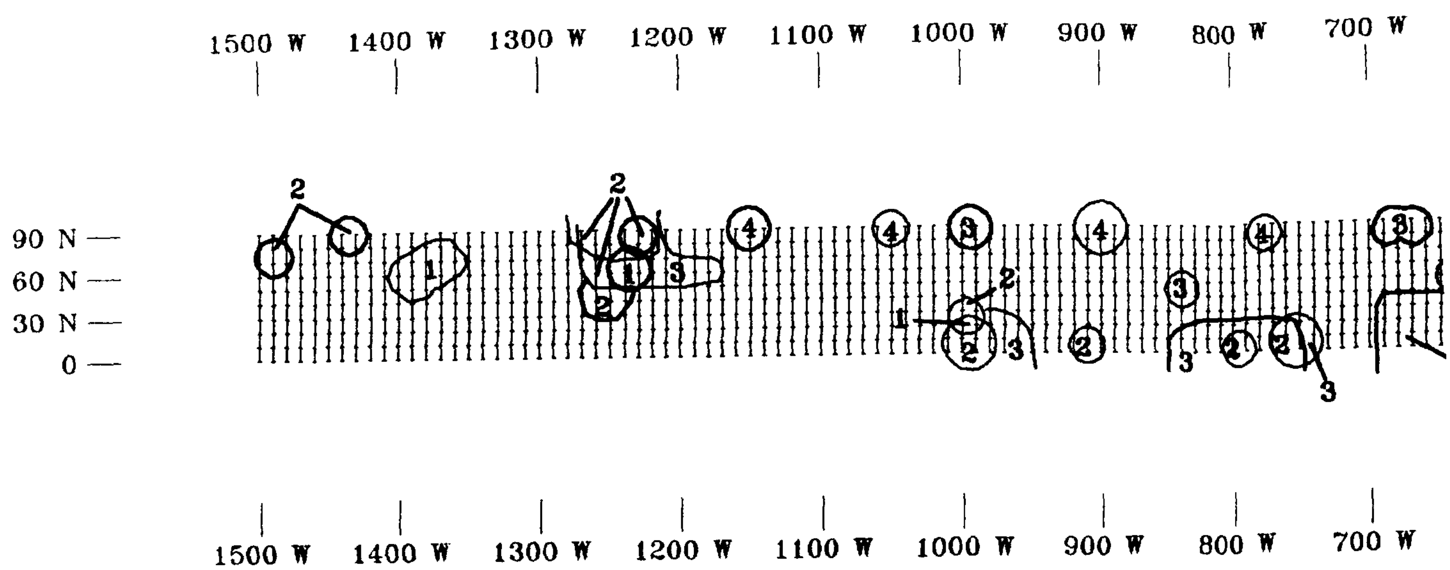
group number.

text.

USATHAMA
ANOMALY GROUP MAP
FORT BUCHANAN PUERTO RICO OCTOBER 1991
USAE CEWES-GG-F (LLOPIS,SHARP)

ap

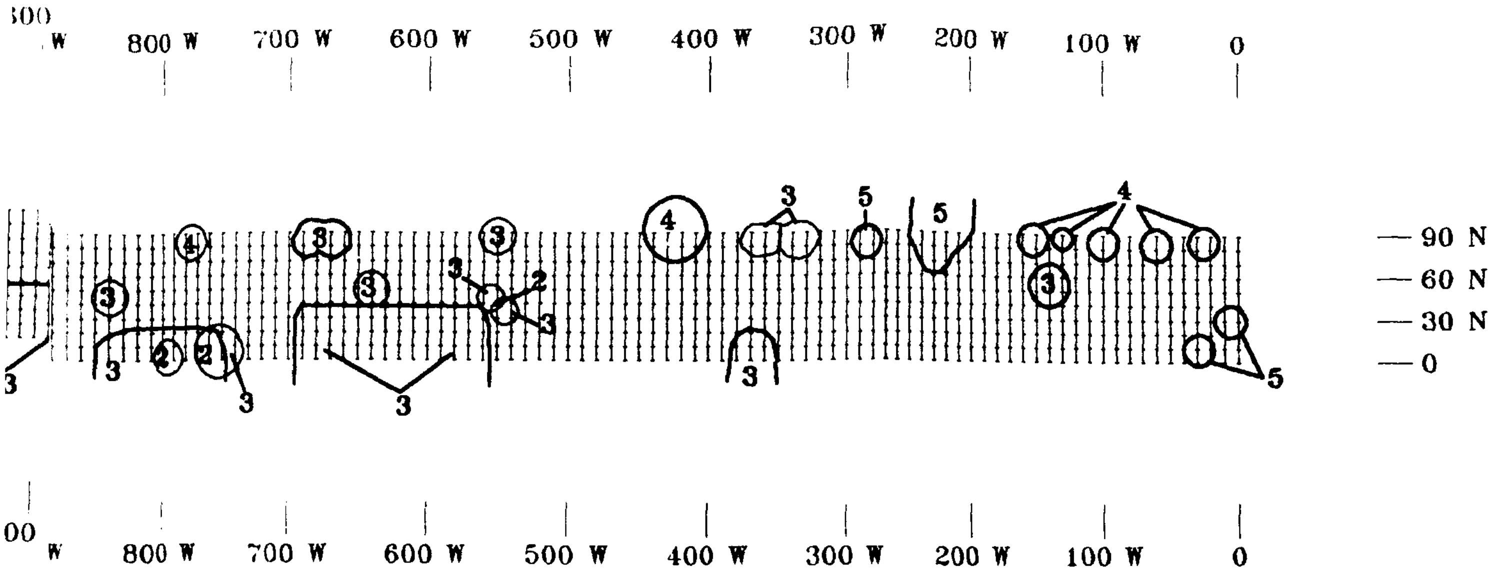
jure 24. Anomaly group map



Investigation Priority

1 Highest Priority
2
3
4
5 Lowest Priority

Figure 25. Anomaly priori



n Priority

t Priority

Priority

Scale 1:1518.937

50 0 50 100 150 200

(feet)

USATHAMA
ANOMALY PRIORITY MAP
FORT BUCHANAN PUERTO RICO OCTOBER 1991
USAE CEWES-GG-F (LLOPIS,SHARP)

map ure 25. Anomaly priority map